Eco-Refrigeration

Proceedings of the Conference on Hydrocarbon Fluids in Domestic and Commercial Refrigeration Appliances

(13–14 February 1996)

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INAUGURAL SESSION

Welcome address

Anil Agarwal
Director, Ozone Cell, Ministry of Environment and Forests, Government of India, New Delhi, India

Respected Secretary, Ministry of Environment and Forests, Mr Krishnan; Excellency Ambassador of Switzerland, Mr Ducrey; Excellency Ambassador of Germany, Mr Elbe; distinguished industrialist and Chairman of Voltas Limited, Mr Tobaccowala; Dr Peter Baz, Head of German Agency for Technical Cooperation (GTZ); Dr Heierli of the Swiss Agency for Development and Cooperation; delegates from Malaysia, Indonesia, and other countries from the East Asian Network; representatives of implementing agencies of Multilateral Fund, the World Bank, and the United Nations Development Programme:

A large number of experts in the field of hydrocarbons (HCs) are present here today (13 February 1996). We extend a warm welcome to all of you on behalf of the three governments – the Government of India, the Government of Switzerland, and the Government of Germany – who have come together on this eco-refrigeration project or Ecofrig as we call it.

The spirit behind the project is nothing but a true commitment to the environment, uncluttered by any commercial interest. It was way back in 1992/93 that initial contacts were made with the Indian industry, and at that time, perhaps, there was a feeling that it was just one of those weird ideas. Since then, we have come a long way. And when you go into details, you find that these natural fluids were being used, actually used, two decades ago.

In the initial stages, the project gave an opportunity to the Indian industry to visit factories in Europe that used natural fluids in the manufacturing process. It also gave an opportunity for Indian research institutions to actually test in their own labs the performance of these refrigerators. This was followed by the involvement of the governments of Switzerland and Germany in 1994, who came forward with financial support, and we provided the framework in which the Indian and the European industry could come together on this Ecofrig project.

The current phase of the project has two components – one is the pilot production of cyclopentane foam, which is used in refrigeration appliances, and the other is prototype testing of compressors using HCs as refrigerant.

You will have a lot more to hear about it in the next two days. Indian industry, in so far as the refrigeration sector is concerned, appears to be at crossroads today. This conference is very timely and has made it possible for a large number of experts to come together. And, it has given an excellent opportunity to the Indian industry to exchange views and charter a course for themselves, which is good for them as well as for the global environment.

Thank you very much.

Address

Guy Ducrey
Ambassador of Switzerland, New Delhi, India

Honourable Secretary, Mr Chairman, ladies and gentlemen – 'Namaste', 'Nihao', 'Guten Tag', 'Buongiorno', 'Bonjour', Good morning:

It is a special pleasure for me to admire the particular achievement of Greenpeace in 'eco-refrigeration'. In 1992, Greenpeace invested DM 30 000 into an ailing East German Company to develop a fully chlorofluorocarbon (CFC)-free refrigerator based on hydrocarbons (HCs). When the prototype was available, they collected 70 000 orders from potential buyers. It is remarkable to see that with such little money a landmark development and a process with far-reaching consequences were set in motion.

For a sustainable success, it needs more than activism. It needs a kind of constructive cooperation among governments, industries, consultants, and scientists, of which the Ecofrig project is a model case. It is based on a constructive collaboration among the governments of India, Germany, and Switzerland. To make this collaboration work, it needs the involvement of large companies from the corporate sector, as well as contributions from scientists and consulting firms. And only if this collaboration is deeply fuelled by a spirit of environmental commitment, it is possible to achieve a real breakthrough. Ladies and gentlemen, the way these different parties, which belong to the 'establishment', have worked together is auspicious.

The Ecofrig project is one of the first projects funded out of a special credit line of 700 million Swiss Francs ($600 million) for global environment, which the Swiss Parliament had sanctioned on the occasion of the 700th anniversary of Switzerland.

In 1992, when the Swiss consultants came to India for the first time, most of the partners were rather skeptical. Consecutive visits of delegations from and to India convinced the partners that a serious shift in technology was taking place in Europe and more and more trust had built up. The cooperation with the participating industries – Voltas, Allwyn, and Godrej – was quite unusual. It is the first time that the Swiss Agency for Development and Cooperation in India has a cooperation with the corporate sector. Surprisingly, this cooperation followed exactly the same principles in partnership development as for other projects; it was based on trust, respect, and a mutual understanding for the possibilities and constraints of the other's situation.

Similarly, the involvement of research institutes – Indian Institute of Technology, Delhi; National Chemical Laboratory, Pune; and Research Centre for Refrigeration and Heat Pumps Ltd (FKW), Hannover – has been crucial for the success of the programme. I had the pleasure to visit Prof. Agarwal's laboratory and was impressed to see refrigerators that he had converted to HCs. The technical inputs have been remarkable; but without the efforts to adopt safety standards, it would not be possible to implement HC-based technologies in India.

We also appreciate the extent and quality of the policy dialogue which this project has initiated among the governments of India, Germany, and Switzerland. India is such a large country that its decisions on the future course are important for the whole world. We are fully aware that the industrialized countries have produced the ozone hole, not India. Our consumption of CFCs, before the phasing out, was 1000 g per capita whereas India's consumption was only 10 g per capita. As an Article 5 party to the Montreal Protocol, India could simply wait and claim the full grace period until the year 2010. Switzerland, Germany, and the European Union, by voluntarily advancing their phase-out deadline, have stimulated innovative steps which have led to the HC revolution. We appreciate that the Indian Government supports solutions that aim at phasing out CFCs in the not-too-distant future.

It is not always easy to manage a trilateral project; we are very happy that Germany has become a partner of this cooperation. We are not only grateful for the contributions of the German Agency for Technical Cooperation (GTZ) to this project, but also for the possibility to create many synergies with China, the other future giant of domestic refrigeration. I am very pleased to see that an important delegation from China has joined this conference and has even sent an HC refrigerator with extremely low energy consumption. I have spent a few fascinating years in the late seventies in China and would like to extend a warm welcome to our Chinese guests.

This conference follows the principle 'act locally, think globally'; it is organized around the Ecofrig project, which is characterized by action and not just by nice words. I do believe that the impact of this conference, through what I would call a multidomestic approach, could even have a global reach. If enterprises in India and

China follow the same strategy, as that of Europe, we would have the majority of the planet converted to HCs.

I am extremely happy that Mr Rahill from the World Bank has joined this conference and has shown much interest in our common efforts. We are very pleased to see that the Bank is listening so well to what Europe proposes as technical solutions for the environment. As you know, European citizens and non-governmental organizations (NGOs) have very high environmental awareness and they are sometimes critical about the less rigid standards on the other side of the Atlantic. By taking this into account, the Bank recognizes our environmental concerns. We do appreciate it.

This conference is a catalyst event. It brings together the world's expertise and experience in HC technology. What once started with a mini-project of Greenpeace has become a significant movement. This conference will bring forward the next steps mainly to cover commercial appliances, which use far more CFCs than the domestic refrigerators. The project will also look into the servicing sector, which consists of thousands of small workshops providing employment to many people.

Let me conclude by expressing my satisfaction about the spirit of cooperation that has brought all of us together today (13 February 1996). It is not to be taken for granted that the three governments, several large industries, a significant delegation from Italy, NGOs, research institutes, and consulting firms can work together in such a constructive way. By involving the small industries and the service sector also in the next phase, this programme may indeed become a model, an encouragement, an inspiration for environment protection, development, cooperation and for a sustainable economic growth. Ladies and gentlemen, we are accountable and we are no more to be denied. May we keep this spirit alive and hand it over like a precious flower to the next generation.

Address

Frank Elbe
Ambassador of Germany, New Delhi, India

Mr Chairman; Honourable Secretary, Ministry of Environment and Forests; Excellency; distinguished fellow members of the dais; and ladies and gentlemen:

It is a great pleasure for me to say a few words on the occasion of the inauguration of the Eco-refrigeration Conference. But it is not without mixed emotions. The pleasure of monitoring the progress made in the field of suitable technical solutions to phase out chlorofluorocarbons (CFCs) remains overshadowed by the global threat of continuing ozone layer depletion. India has reached a decisive step on the long journey to overcome scientific and economic hurdles that would stand in the way of its compliance with the 1987 Montreal Protocol on the protection of the ozone layer: to achieve its ambitious goal by 2006 – to phase out the production of ozone-depleting substances (ODS). The decision on which path to follow has to be taken this year (1996). I would fail to lecture on the science of hydrocarbons or hydrochlorofluorocarbons. However, I do recognize the burden that has been laid on your shoulders: to choose between a substance which still has a high global warming potential – possibly only a transitional substitute – and a substance that is flammable but has the merits of a natural fluid and is not ozone-depleting.

Germany made its choice after much political efforts. And we further opted together with Switzerland to lend our support to any country taking up the challenge. In addition to our commitment to the Global Fund of the Montreal Protocol, we pledged additional bilateral assistance also to India. Our trilateral Indo-Swiss-German project bears witness to this.

Thus, many of you by now have a long-lasting research experience with Foron. It is in light of this experience that India can meet the expectations of the Montreal Protocol but also of its citizens. How to provide a growing and increasingly prosperous population with economically feasible solutions – also for refrigeration. The need for professional training, creation of workplaces, safe household appliances, and a sound servicing and repair chain is an eminent economic challenge. This by its nature has to consume and deplete resources.

On the other hand, there is an increasing environmental consciousness. This is the case around the globe, as it is a genuine global challenge. Thus the consciousness with regard to the need for bringing together conflicting interests for the protection of our natural environment and for economic development has grown. I am not referring to the Montreal Protocol on ODS. I would rather refer to an American philosopher of German origin, Hans Jonas, who has worked throughout his life on developing the principle of responsibility. His logic was a very simple one. He said that our responsibility goes beyond our times, that it relates to future generations, to our children and grandchildren. What he actually had in mind was a responsibility that stems from the new technological means that man may or may not command properly. Man is to use his means in such a way that the final effects would not be felt by future generations. Jonas's theme was the protection of the natural resources of our planet, but equally the creation of an environment that would be conducive to a quality of life, which would respond to the culture and the civilization of our societies. He called upon us to leave to our future generations more than the mere administration of our failed policies.

I think it is very much in the spirit of the principle of responsibility and its new dimension in time that you have accepted the challenge in your work. You acquired the know-how to develop appropriate technological solution for India's contribution to the global goal of phasing out CFCs. In this respect, I wish to congratulate you on your sense of responsibility and on accepting the challenge of developing the prospects of the Indian refrigeration industry with increased output and the guarantee to customers and mankind alike, that, yes, there is life after the refrigerator.

Thank you very much.

Remarks

Peter Baz
Head, GATE, German Agency for Technical Cooperation (GTZ), Eschborn D, Germany

Honourable Secretary, Excellency, Mr Chairman, distinguished guests, and colleagues:

First of all, I want to thank the Indian and the Swiss partners for their constant and intensive cooperation in these projects and programmes.

It was about four years ago that I convinced our ministry and my own organization, the German Agency for Technical Cooperation (GTZ), to initiate bilateral programmes and projects to protect the ozone layer in close projects in the refrigeration sector. So roughly two years ago, we started these two pilot projects in China and India. In China, we realized, it is the first conversion cooperation with the US Environmental Protection Agency. Our partner in China is Haier company. I am happy to have the Vice President of the Haier company, Mrs Yang Mian Mian.

The second pilot programme we undertook, together with our Swiss friends, Swiss Agency for Development and Cooperation and Infras, is this two-day conference on 'Ecofrig'. I hope this conference will give detailed information for a right solution. As pointed out by other speakers, it is difficult for enterprises and governments of the countries to take a right decision for the best solution to phase out ozone depleting substances in the production and servicing of refrigerators.

We have decided to support those companies and countries who want to know more about hydrocarbon (HC) solutions, as our country is very experienced after being in this field for several years. So I offer this assistance and support for preparing feasibility studies to those companies who are interested to get qualified information for their decision.

The most essential principle of our phase-out support is that this assistance and guidance is given only through experienced personnel who went through the process of factory conversion to HC technology themselves. And I am happy to have these colleagues from different companies here with us. Since the bilateral support is limited, I must say that those companies and countries who ask for our support first, will get it quickly.

Thank you.

Keynote address

A H Tobaccowala
Chairman, Voltas Ltd, Mumbai, India

It is with much hesitation that I agreed to speak to this distinguished gathering as the conference is to discuss issues which are complex and highly technical. However, the problems which the conference will deal with concern all of us. None of us can be oblivious of the progressive and accelerating damage caused to the earth's environment, especially in recent decades. Responsible citizens, even of developing countries, cannot adopt a passive or indifferent attitude merely because the issue is complex or because of lack of unanimity among experts. Least of all can we seek shelter behind the important fact that much of the environmental damage, including the specific types with which the conference is concerned, has been caused by the developed countries of today and not by the developing world. Both as a citizen and as a person very much involved in the refrigeration industry, I realize that the problems of ozone depletion and of global warming are of intimate concern to my organization and to me and that we have an obligation to accelerate preventive action against the catastrophic consequences. Eco-refrigeration is one important solution.

I hope I will be first permitted a little mischievous digression especially as, at this morning's inauguration, there are, like me, so many non-specialists who are present as concerned citizens and not as contributors to technical issues. Ozone depletion and global warming have been subjects of very serious concern for many years. Large resources have been expanded on seeking solutions and equally on creating pressure on all countries and all people to take early corrective action. These dangers, which are very real even if not immediate, do very much affect us as well as the other poor or under-developed countries. However, you can understand the somewhat cynical view expressed by many in the poorer countries that similar attention is not given to more imminent threats to them such as malaria, tuberculosis, and so many other life-threatening conditions. It is only when threats, including AIDS, affect the developed countries that the world's conscience is stirred and its purse strings are loosened.

Moreover, even in a grave situation about which this conference is concerned, economic interests do seem to play an important role. For years, the gospel was that the only substitutes to CFC11, 12, 22 *et al.*, which had to be eliminated, were other synthetic chemicals such as 123, 134a, and the like, together with newly developed lubricants – all of them, of course, more expensive than the deleterious substances they were intended to replace. In this process, there was inevitably enormous economic advantage to a few corporations to whom the world's problem became a business opportunity. While funding through the Montreal Protocol is being provided to eliminate chlorofluorocarbon (CFC) using equipment and processes, I would think that producers of non-CFC synthetic refrigerants, who have been so vigorously promoting their products, would have been prompted by world opinions and their governments to make CFC substitutes available to developing countries at prices comparable to CFC refrigerants. The producers could be appropriately compensated by subsidies or other measures.

I am sorry to have started my address on a note of dissidence; but I do wish to reiterate that as a representative of the Indian corporation, which is possibly the largest user of hydrochlorofluorocarbon (HCFC) products, we have not only accepted the responsibility of phasing these out as rapidly as possible but are also grateful to the international community for its willingness to fund some of the transition processes.

I must particularly express our gratitude to the European governments and corporations, especially those of Switzerland, Germany, and Italy, for their tireless and successful efforts to convince us that synthetic chemicals could be substituted by hydrocarbons (HCs). We are grateful to them not only for the financial and technical assistance they have given but also for the learning process for which they have provided technical personnel and the testing of our products for HC use. I would also like to express our sincere gratitude to the governments and organizations which have offered assistance in setting up pilot plant facilities for cyclopentane as a blowing agent which will dramatically reduce CFC use initially by Voltas, Godrej, and, I hope, very soon thereafter, by other manufacturers of refrigeration and insulated equipment. We assure you that we will do our best to use this equipment effectively; we will provide the necessary additional resources to ensure their efficiency; and we will share freely and fully all that we learn about the safety aspects of using cyclopentane as a blowing agent.

I realize that much of this conference will concern itself with the elimination of CFC refrigerants and the complex problems associated with it. Speaking as a person wholly ignorant of scientific understanding and looking at the problem from a practical and pragmatic view of business, I am concerned about several issues.

Firstly, the process of converting our existing refrigeration equipment to non-CFC is proving to be both slower and costlier than we anticipated. While many of us have not been quick in seeking the financial assistance available from inter-national institutions following the Montreal Protocol, our impression is that the process of approving funding applications is slow, that the purposes approved are highly circumscribed and that the technology inputs we need for the conversion are not being made available with the facility and at the cost we anticipated. In fact, much of the international funding for CFC conversion is going back to the donor countries in the form of technology fees or the higher cost of the refrigerants and lubricants that the non-CFC equipment will require. The actual financial assistance received through the Montreal Protocol tends to be exaggerated. At the same time, the producers of CFC refrigerants in the developing countries are concerned about the economic consequences on them of the CFC phase-out. Many of you here are in a position to influence the speed and processing of funding; I do urge that you assist in ensuring that there is greater understanding of our problems and the resources available are larger and also disbursed more speedily.

Secondly, a large number of producers of refrigeration equipment, particularly those in the US and Japan, are committed to using synthetic chemicals and not HCs as refrigerants. Products using such refrigerants have gained wide acceptance in India and other developing countries partly because they have been widely proclaimed as safer. In such an environment, it would be extremely difficult for us to use HCs as refrigerants both from the marketing standpoint and even more for reasons of servicing equipment. It would be impossible for the same service personnel with limited skills to deal with equipment using CFC and non-CFC chemicals as well as HCs as refrigerants.

Thirdly, again as a result of intensive marketing effort, principally by overseas producers and their representatives, the frost-free refrigerator is gaining wide acceptance in India and other developing countries. Till such time as products using HC refrigerants are available at the same cost with similar facilities and of similar size as units using synthetic chemicals, any manufacturer seeking to use HCs would be at a disadvantage.

Fourthly, air-conditioning and refrigeration of transportation equipment, which was exceptional a few years ago, is now gaining popularity and a larger percentage of the growing automobile population of India is air-conditioned. It is important that refrigerants to be used with safety in these appliances should be determined as quickly as possible.

Lastly, as a major producer of larger air-conditioning plants including packaged units, centrifugal chillers, screw compressors and the like, we are interested in assessing how effectively HCs can be used in such appliances. What are the acceptable substitutes to CFC22, 123, and 134a? I know that there is a strong resistance against major changes in refrigerants used in large installations, especially if they entail the elimination of synthetic chemicals.

I am sure that by the end of this conference, there will be better understanding and greater agreement on these and allied questions. All of us, who are both interested in the problems in our professional capacities and also as citizens concerned with the problems forming the theme of this conference, wish the participants two fruitful, interesting, and constructive days of deliberation.

This conference takes place at an opportune time when so much progress has been made in finding substitutes for CFC refrigerants and blowing agents. It is even more important because so many issues about the selection of suitable long-term refrigerants and blowing agents need to be quickly resolved. I am sure that the Indian industry will cooperate wholeheartedly in the worldwide efforts to find solutions to problems which are global in nature. I would also like to assure on behalf of myself and my organization that we are willing not only to cooperate with the world community but also to undertake the necessary experimentation and to provide the requisite resources to assist in our small way in the global efforts to avoid grave ecological changes. This eco-refrigeration conference is an outstanding example of these efforts.

Address by chief guest

N R Krishnan
Secretary, Ministry of Environment and Forests, Government of India, New Delhi, India

Good morning to you, your excellencies, my very distinguished colleagues of the day, and ladies and gentlemen:

It would be most inappropriate to extend a warm welcome to a refrigeration conference. That would be a contradiction in terms. However, let me, following the tradition, welcome you all and especially the foreign delegates to this country. This is a very lovely season in New Delhi and a good time to be in India and to go around.

It is very appropriate that this gathering is being organized at the initiative of the Swiss and German governments. I have a very exaggerated respect for these two nations because, as one of my distinguished seniors, who is among the audience, would agree, if you open any page on Chemistry, you find about half a dozen Swiss and German names. And of course, we have all heard of the Teutonic thoroughness. In this context, I am reminded of a story which I once heard in the World Bank. They cannot claim intellectual property rights on this, as it is just a joke. A group of scientists – an Englishman, a Swiss, a German, and an American – visited India to study the Indian elephant. The Englishman went back home and wrote a two column article in *The Times*, London. The Swiss wrote a monograph on how to make the movements of the Indian elephant more precise and elegant as he found the elephant a bit ungainly in its movements. The German went back and wrote a book in two volumes of thousand pages each and entitled 'A very preliminary introduction to the Indian elephant'. The American wrote in the *Harvard Business Review* 'How to make bigger and better elephants'.

The subject you shall be dealing with today (13 February 1996) and tomorrow (14 February 1996) is something with which I have had the privilege of cultivating some familiarity in the last few years. Way back in 1990, when I was working in the Ministry of Industry, the Ministry of Environment and Forests had set up a task force on the strategy to phase out ozone depleting substances (ODS) in this country. Based on whatever knowledge that was available to us at that time, we drafted a strategy fully realizing that nothing indeed was permanent and things would undergo change as more and more commercially proven technologies come into the market. We also kept in mind the growth in the use of ODS in this country, the fact that there was a phase-out schedule agreed to in London, and the fact that a new phase-out schedule for the developing countries, known as Article 5 countries, was going to be worked out in the year 1995.

It has been my good fortune that when I moved in to this ministry, I became the co-chairman of the Inter-governmental Working group set up by the Conference of Parties to the Montreal Protocol. The other co-chairman was from Denmark, Mr Carstenson. He represented the developed countries and I represented the developing countries. I should consider myself privileged indeed in that in the last Vienna meeting of the parties in November–December 1995, certain important decisions were taken. The Vienna meeting was expected to decide whether a phase-out earlier than the one prescribed should be adopted for the developing countries or not.

What one has been able to see particularly in the Montreal Protocol is that suddenly some scientific fact is discovered, which is realized to have a global effect, and the entire global community is called upon to share the responsibility of meeting this challenge forgetting for a moment as to who really contributed more to the problem and who contributed nothing at all. In fact, as you know, as per the Montreal Protocol, an Article 5 country is the one where the per capita consumption of ODS is less than 0.3 kg per capita per annum. India consumes far less than this and even the most optimistic growth estimates would not take us to this level at all. So the question naturally arose why countries, which consume very little ODS, should share in this global endeavour. But then we do realize our commitment to the global environment, and hence accepted the principle of common and differentiated responsibility.

We have a common responsibility to protect the global environment; at the same time, our responsibility is also differentiated in it. It cannot be of the same magnitude, as that of the developed countries who in the first place are responsible for many of the global ills. This underscored the debate in the last 18 months in forums where phase-out schedules were being discussed.

A lot of problems arose and it was very interesting to see how technological innovations made in one country or the other started translating themselves into global politics. A very good example is the one with which you will be grappling in the next two days – the rise of hydrocarbon (HC) technology in refrigeration.

Hydrochlorofluorocarbons (HCFCs) are being used fairly extensively in many parts of the world including China. HCFCs are safe from the ozone depleting point of view but not from the global warming point of view. What happened in Vienna was that, even among the developed countries, which are collectively known as non-Article 5 countries, a strong cleavage of opinion developed as to whether the HCFC phase-out should be brought forward or not and that affected the provision for non-Article 5 countries as to when they should have their phase-out. Whether it should have been 2040 as decided earlier or it should be brought forward. Some of you must have been a witness to the debate in the last hour on the last day of the Vienna conference. There was a strong debate in which one saw many things in the raw – global politics, commercially-driven arrangements – and then suddenly we had the methyl bromide phase-out.

The entire Group of 77 and China fought on behalf of some of their brethren for whom methyl bromide was a matter of life and death. Kenya, for instance, used methyl bromide in fumigating coffee plantations. However, in a spirit of cooperation, the Article 5 countries agreed for a freeze on the use of methyl bromide by 2002. When it came to HCFCs, there was a strong difference of opinion between the United States and the European Community. And finally, it was decided that for Article 5 countries, the HCFC phase-out may begin by 2016, with 2015 as the base, and be completed by 2040.

The agreed phase-out schedule for HCFCs gives a fairly long interval of time so that the industry in Article 5 countries can consider and exercise the option whether to go in for HCFCs now and convert to HCs later or go to HC technology right away. It is the availability of technology, the ease with which it is transferred, and the availability of funds for this purpose that are going to determine which route one is going to follow and how quickly this transformation is going to take place.

Honestly, the ministry is disappointed with the Indian industry, particularly the refrigeration and the air-conditioning sector, for not taking active steps to decide which course to follow, that is, whether to follow the HCFC route or go to the HC technology. We have been highlighting in world forums the difficulties in securing technology and in its transfer, and the terms that accompany such transfers. In fact, Article 10 of the Montreal Protocol lays down very clearly that the phase-out is contingent upon the availability of technology and its transfer and availability of funds for this purpose. On both accounts, I do not think the position is very rosy. That is a good reason why I look up to this gathering with a feeling of expectation and hope that at last Europe has come forward to share with us the HC technology.

Mr Tobaccowala has brought out where we stand in respect of these developments. And, we need to be fully convinced that the HC technology is going to answer the problems, particularly in a country like India where servicing of the equipment is done by a very large number of people and how to ensure consumer safety while using these HCs.

We have a long time to go for the HCFC phase-out, which is to begin in 2016. Perhaps, that itself is an incentive for the European chemical giants who have developed the HC technology to come and spread it before the HCFC starts making inroads in this country.

Funds are indeed a problem. The funds with the Montreal Protocol are limited. And with the existing procedures, you can never be quite sure whether the criteria applied in an earlier case would be applied to your case also. Because of the shortage of funds, suddenly new criteria are applied so that less and less is given from the Fund. This is a matter we are very deeply concerned with and we had taken it up with the Executive Committee of the Protocol on more than one occasion. India was elected last December as a member of the Executive Committee for this year (1996) with Kenya as the Chairman. Certainly in the Executive Committee, we are going to voice these feelings freely and strongly. At the same time, we should also expect the Indian industry to come forward with proposals. The days of thinking, dallying, and dithering are over. In fact, we are seriously considering introduction of a legislation. A signal should go to the Indian public very soon and we are trying to work on the type of legislation that would be required so that the industry and the Indian consumer get the right message on time.

Till recently, one used to hear of the difficulties in obtaining technology. Now with a gathering like this, one can see a willingness on the part of those who have the technology to transfer it to those who need it. We should make full use of these opportunities and I should expect to see the Indian industry rising up to the occasion and take full advantage of these offers especially since the phase-out for Article 5 countries is finally settled. The dust of the battle has settled down and it is time for us to go forward. I look forward to the appearance of the first eco-friendly refrigerator in the market and to whosoever who may introduce it, my humble request is to invite me for that occasion.

Thank you.

Concluding remarks and vote of thanks

Urs Heierli
Head and Counsellor, Swiss Agency for Development and Cooperation, New Delhi, India

Honourable Secretary, Mr Chairman, ladies and gentlemen:

When the Ecofrig project started in 1992, we could not have even dreamt of such an important conference ever taking place. At that time, shortly after Rio, we had a lot of enthusiasm in our heart, but no solution in our pockets. Switzerland was working on vacuum insulation; and in Germany, 'Greenpeace' was talking of a 'green' fridge.

The reaction of the industry came accordingly; there was a lot of scepticism. Our friends told us recently, after we established a high degree of mutual trust, that they initially had considered our proposals to be a 'joke'. It all seemed much too fantastic to be true.

In 1993, we invited a delegation of Indian scientists and industry representatives to Switzerland and Germany. They came back and told their colleagues: 'no, it's not a joke'. Although it is hard to believe, this 'green fridge' with a mixture of propane and butane does indeed work.

However, it took a year more for a real breakthrough. In the summer of 1994, a high level delegation from India, headed by two secretaries of the Indian Government, participated in the first conference on natural fluid-based refrigeration in Hannover and witnessed the changeover to hydrocarbons (HCs) by the entire German refrigerator industry. At that stage, the core piece of the Indo-German-Swiss Ecofrig cooperation started and the decision was taken to establish two pilot foaming plants with Voltas/Allwyn in Hyderabad and Godrej in Mumbai. These pilot plants will arrive in India in the coming weeks and will test the suitability of cyclopentane foaming under Indian conditions.

The development in HCs in the last four years has been mind-boggling. This conference brings together the world's know-how on eco-friendly refrigeration technologies and sets the stage for the exposure of the progress made so far. You may see the first frost-free isobutane refrigerator developed by Liebherr; you will also see a Chinese isobutane refrigerator with an extremely low energy consumption. All this is possible only because of an extremely constructive form of cooperation across the board; it is astonishing and rewarding to see how well so many different institutions have been working together.

Let me express, Honourable Secretary and the Chief Guest, our sincere thanks for your address and your presence in this inaugural session; please let me add our gratitude for the stimulating cooperation with your ministry: we always have an easy access to your colleagues and find all the support and understanding needed for this project.

My sincerest thanks to Mr Anil Agarwal, Director of the Ozone Cell, who has always been an open and very competent discussion partner. With him, the Ecofrig cooperation has become a partnership among the three governments, always respecting different national interests and perspectives and seeking the common goal.

The cooperation with our industrial partners has also been very interesting, fruitful, and cordial. I would like to thank you, Mr Tobaccowala, and also Mr Crishna from Godrej for this cooperation, which is a new experience for us and probably for you too. Let me thank Mr Chairman for coming to Delhi and delivering the keynote address.

Your Excellency, Mr Elbe, Ambassador of Germany; and my colleague and friend Peter Baz of German Agency for Technical Cooperation; before I thank you for your contribution, please let me confess that, initially, I was not so sure whether it was a good idea to involve three governments rather than two. Today, however, when I reflect on the role of German technology and see the synergies between the programmes in China and India, I am really grateful for your full involvement and support. Dear Mr Elbe, dear Peter Baz, let me warmly thank you not only for your contribution but also for the strong partnership that has emerged from our cooperation.

I would also like to thank my Ambassador, Guy Ducrey, for his support and understanding of the Ecofrig Programme. We often had good discussions about this project and it was one of the first agreements he signed after his arrival in India.

I could not conclude this inaugural session nor finish my vote of thanks without mentioning those who have organized this conference – Infras and the Tata Energy Research Institute. Without the commitment and the competence of the whole team, working sometimes round the clock, I can assure you, nobody would have had a hotel room, food, folders, badges, papers, registrations, invitations and all that is necessary to accommodate such a big crowd comfortably. I simply would like to thank all of them very, very warmly.

SESSION I

COOPERATION – EXPERIENCE AND BACKGROUND

Observations on the status of hydrocarbon technology in domestic refrigerator markets – Western Europe with global prospects

Othmar Schwank
Managing Director, Infras AG, Zurich, Switzerland

Hydrocarbon refrigerants

Background

Prior to the discovery of the chlorofluorocarbons (CFCs), hydrocarbons (HCs) were widely used as refrigerants in domestic and commercial refrigerators. They were gradually replaced with CFCs due to its non-flammable nature. The revival of the HC technology in Europe during the early 1990s is likely to turn out as an interesting piece in the history of technology. The high global warming potential (GWP) and the incompatibility with mineral oils of HFC134a (hydrofluorocarbon) made researchers and manufacturers of equipment look into the group of so-called natural fluids as refrigerant alternatives to CFC12. So HC refrigerants, requiring only well-known technology with respect to the refrigeration cycle, were reconsidered. For safety-related design, proven technology from petrochemical appliances was available. Different tests with HC refrigerant were made in the late 1980s; however, no manufacturer was prepared to announce an HC-based domestic refrigerator until 1992.

In 1992, the year of the Rio Conference, the Copenhagen Amendment advanced the CFC phase-out date to 1 January 1996 for Article 2 countries. Prior to Copenhagen, the European Union (EU) had announced to phase out CFCs by 1 January 1995 while Germany's manufacturers volunteered for an earlier date (mid-1994). Manufacturers were put under strain to come out with green refrigerators by 1993. In 1992, Greenpeace (a non-governmental organization concerned with environment), with an effective media campaign and R & D contribution of DM 30 000, supported the East-German manufacturer Foron for developing the first modern HC refrigerator based on a propane/isobutane blend. The introduction of this technology forced larger refrigerator manufacturers to prove their ability to develop similar models.

The media presence and sale success of the Foron refrigerator, backed by an environment award and the environment label 'Blue Angel', did move up CFC/HFC-free products put into market by the other two German HC pioneers Liebherr and Bosch-Siemens. These two manufacturers launched the first isobutane/cyclopentane refrigerators.

In order to meet the 1994/95 CFC phase-out dates, these companies and the players associated to the Whirlpool Group (Bauknecht) and the Electrolux Group (AEG) had to convert the bulk of their models to HFC134a. Fifty per cent of the R & D work had been completed by fall 1992. Then the landmark decision in favour of HCs was taken within Germany's refrigerator manufacturer's association, to which the German Environment Ministry significantly contributed by questioning the rationale behind the 'HFC134a only' position so far taken by the manufacturer's association. Foron was the only manufacturer who did not first convert to HFC134a. Informally, Liebherr and Bosch-Siemens confirm that they have never regretted the landmark decision of fall 1992 facilitated by them, and they ultimately got rid of the HFC134a related problems experienced by them between 1992 and 1994. This was possible due to the launching of the R & D masterpiece, isobutane refrigerator models, within a span of only six months.

Isobutane vs. *hydrocarbon blends*

For taking the lead in conversion to HC refrigerants, Foron benefitted from the strategic advantage of still producing its own compressors. This put Foron into a position to launch a simple conversion solution. Foron's conversion criteria were safe product and, at least, CFC12 equivalent performance at minimal conversion cost for compressor and refrigerator design adjustment. The conversion to a blend of propane (HC290) and isobutane (HC600a) matched the cooling capacity of CFC12 with a given compressor displacement almost exactly. Thus any major conversion of compressor production was avoided.

The HC blend, as compared to CFC12, does have, besides flammability, demerits such as slightly higher noise, the problem of temperature glide, and the possibility of a differential leakage. Compared to blends, the merits of HC600a (being a single refrigerant) are its higher energy efficiency and lower noise. The major players in the German market accordingly gave preference to HC600a.

HC-blend compressors, fulfilling the requirements of high energy efficiency and lower noise, could not be developed within the six months time, i.e., between the landmark decision in favour of HC refrigerant and the introduction of the Foron refrigerator into the market. The first HC compressors freely available in the market were HC600a compressors produced by Danfoss. The warranty for this compressor was granted only later. The fast-growing market for isobutane refrigerators took some big players in the compressor business by surprise. They had invested heavily in HFC134a conversion and were not prepared for an almost simultaneous second conversion to HCs. So, the limited supply of compressors, together with the above-mentioned isobutane merits, made the preliminary selection of HC600a an acknowledged standard.

Development of market shares: hydrocarbon compressors

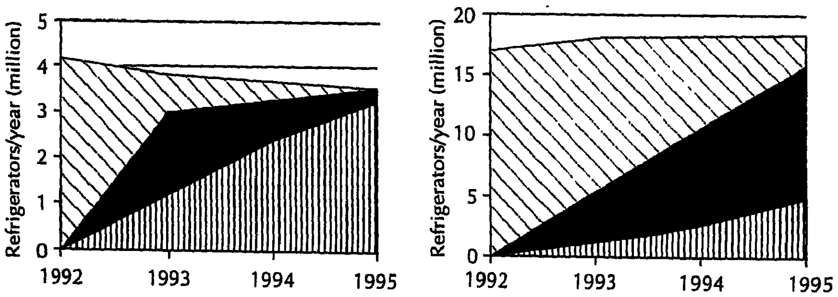
By 1994/95, the European factories of Electrolux, Zanussi, Unidad Hermetica, and Verdichter Oe had started producing HC600a compressors on a large scale. The European subsidiary of Embraco Brazil, which, in turn, belongs to the Whirlpool group, has been catering to a sizeable portion of the growing Western European HC600a compressor market. Matsushita, after losing some of the previous HFC134a market share, had introduced its own HC600a line for the European market. Americold, being a subsidiary of Electrolux group, is the only North American compressor manufacturer to have launched an HC600a prototype production. Independent Western European compressor manufacturers are Danfoss in Denmark, Necchi in Italy, and Foron – all of them manufacturing a large number of HC compressors. Danfoss is estimated to be the leading manufacturer with approximately 2.5 million compressors sold in 1995. The total market volume of HC600a compressors in Western Europe is estimated at four to five million units for 1995. The share of isobutane compressors within the domestic refrigerator market is rapidly increasing. The market of small plug-in commercial appliances started to grow for isobutane compressors recently. The global market share of isobutane compressors may, in 1995, have reached six per cent of a total volume of the estimated 70–80 million compressors (as compared to some 35%–40% of HFC134a compressors). The experience gained from the European market, where manufacturers had the chance to test both the technical options (HFC134a and HCs) on a large scale, suggests that HCs would be a preferable option to convert the remaining half of CFC12 compressor production. Technical, economic, and ecological evidence does support this conclusion (FKW, Infras 1996).

The purchasing power of global markets, yet to be converted from CFC12 to a non-ozone depleting substance, is less; so is the cleanliness of the industrial manufacturing and servicing conditions. Therefore, the considerations which made Foron choose HC blends initially may have to be re-evaluated. It had also operated in lower purchasing power segments of the German market. Taking into account similar experiences from the Italian market, Necchi has developed a parallel line of HC-blend compressors showing good results (Biscaldi *et al.* 1996).

Development of refrigerator market shares

The introduction of HC refrigerators has been consumer-driven. Big warehouse groups had taken a lead in the German market. Since Germany is the most important market in Western Europe, particularly after reunification, other European suppliers had to launch HC refrigerator production as well. Due to short supply of HC compressors, most West European countries converted to HFC134a first. Outside Germany, sales of HC refrigerators picked up sizeable amounts only during the year 1995. Therefore, the present market share of HC refrigerators in Western Europe is approximately 25% (Figure 1).

By 1995, safety regulations were gradually legalized within the EU (British Standard 4434, DIN 7003, etc.), and formalized in an international standard as well. These standards have become the guidelines for manufacturers who had not yet converted to HC. These guidelines and increasing demand for safety components have reduced the production cost of HC refrigerators compared to the pioneer conversions of 1993. Production costs of HC refrigerators do range between the CFC12 and HFC134a technical option. The sales trend for HC refrigerators past 1995 will



(a) Germany (b) Western Europe

Note: ▨ CFC12 ■ HFC134a ▥ Hydrocarbon

Figure 1. Refrigerator market and market share of HC refrigerators in Germany and Western Europe between 1992 and 1995 (estimate)
Source: FKW/Infras 1996

be set by comparative performance, service network, and marketing strategies adopted in other European countries other than Germany. Preliminary observations during 1995 indicate that the demand for HC refrigerators will pick up faster in the European countries, especially in the North of the border separating the Roman and German-based language groups (Table 1). This observation is related to a cultural difference and is reflected in, for example, different approaches to product liability legislation or a higher willingness to pay for conservation of natural resources among the people of Northern Europe. It is related to different valuations given to common property within the historical German and Roman legal systems.

Foam

The European manufacturers had reduced the use of ozone depleting substance (ODS) in foam-blowing in several steps. In the first step, the content of CFC11 in the foam was reduced from 120 g/kg to around 60 g/kg foam. This went on till 1993.

The next step considered was to completely phase out CFC11 using HFC134a or HCFC141b (hydrochlorofluorocarbon) as substitute blowing agent. This conversion strategy was in a stage of internal evaluation in mid-1992 when the Copenhagen Amendment of the Montreal Protocol to advance CFC phase-out date

Table 1. Domestic refrigerator sales trends in Western Europe by refrigerant (CFC12, HFC134a, HC600a) (estimate)

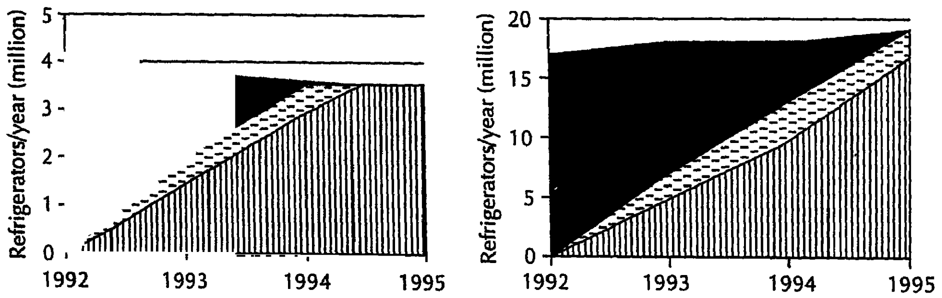
		Domestic refrigeration sales		
Region	Refrigerant	*1993*	*1995*	*1997 (forecast)*
North-west Europe				
	CFC12	40%	10%	0%
	HFC134a	40%	50%	20%
	HC600a	20%	40%	80%
Total no. of units		10 million	10 million	10 million
South-west Europe				
	CFC12	60%	15%	0%
	HFC134a	30%	75%	60–70%
	HC600a	10%	10%	30–40%
Total no. of units		9 million	9 million	9 million

Source: Infras (based on personal communication with marketing departments of refrigerator manufacturers).

in Article 2 countries by 1 January 1996 took shape.[1] During 1992, majority of the manufacturers catering to the German market decided to convert their foaming processes to HFC134a. The HCFC141b technology favoured by US manufacturers was not seriously considered in Europe due to the second conversion needed around 2000. This technology was not proven in 1992. Manufacturers who had converted to HFC134a used it only for a short time as foam-blowing agent. The landmark decision within Germany's manufacturers' association to accept a flammable refrigerant, turned the scene in fall 1992 also in favour of cyclopentane as foam-blowing agent. Liebherr and Bosch-Siemens converted their foaming lines to cyclopentane in spring 1993. The other German manufacturers then gradually reconverted from HFC134a to cyclopentane as well. Most of the European manufacturers, who had to meet the EU conversion date of 1 January 1995, achieved a market share of nearly 100% within Western Europe (Figure 2).

In Western Europe, preference was given to cyclopentane as foam-blowing agent due to technical and non-technical considerations given below.

- Negligible GWP compared to HFC134a.
- Zero ODP, no second conversion past 2000 is needed if HFCF141b had been chosen. This technology was not proven till 1992.
- Accelerated CFC phase-out schedule adopted by EU made a technology decision mandatory in late 1992.



(a) Germany (b) Western Europe

Note: ■ CFC11 ▤ HCF/HFC ▥ Cyclopentane

Figure 2. Market shares of refrigerator foam blowing agent (CFC11, HFC/HCFC, cyclopentane) in Germany and Western Europe between 1992 and 1995

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[1] Personal communication with Rolf Segerström of Electrolux in Zürich, July 1992

Conclusions

The HC technology in domestic refrigerators succeeded in Western Europe mainly due to the following technical and non-technical co-founding factors.

- The advanced phase-out schedule of EU for CFCs had put manufacturers under pressure to decide technical options ahead of time as compared to manufacturers in the US or Japan. Secondly, the EU had also regulated the use of HCFCs in new appliances. These policies shaped the choice of cyclopentane as foam-blowing agent.
- The adoption of cyclopentane was facilitated after R & D departments of German manufacturers had acknowledged the strategic advantages of converting to HC refrigerant in fall 1992 – for technical rationale. Accepting a flammable fluid in foam-blowing and as refrigerant had facilitated each other.
- There was a strong demand for an ecologically sound product. So, the refrigerator manufacturers converted the refrigerant twice – first from CFC12 to HFC134a and second from HFC134a to HC600a.
- After establishment of the HC technology on the market, the technical rationale will gradually lead to complete replacement of HFC134a by HCs. This process has started spreading to commercial appliances.

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The twelve advantages of hydrocarbon technology: a personal opinion

Klaus Meyersen
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Introduction

My considerations deal mainly with the use of hydrocarbons (HCs) as refrigerants (isobutane, blends of propane/butane), since this application of HCs raises most of the questions. Cyclopentane has already been firmly established as the world-standard foaming agent for the insulation of household appliances. It will, therefore, only be mentioned in passing.

I would like to point out that the aspects of HC technology presented here; the views expressed on this technology *vis-a-vis* the Multilateral Fund of the Montreal Protocol are my personal opinion. As I am frequently asked about various aspects of HC technology and the present situation within the Multilateral Fund of the Montreal Protocol, I thought it might be useful to put my knowledge in writing, and thus take advantage of my contacts at various levels of the Montreal scene to pass on this information. I express my view primarily as advisor to the Federal German Agency for Technical Cooperation (GTZ), which promotes HC technology. I also convey my observations from and to many Multilateral Fund meetings and committees – such as the Executive Committee and the Ozone Operations Research Group – dealing with this technology.

On the one hand, the introduction of HC technology in domestic refrigeration industry has gained astonishing momentum in recent months. On the other hand, large political and administrative bodies, such as the Montreal Protocol, are so slow in facilitating information flow to the 'executive level' (by which I mean the level of the people actually using it!). So I hope to help accelerate the information flow within the wider scope of the Multilateral Fund and Global Environment Facility (GEF) up to the speed at which this new technology is gaining ground. I hope the 'executive level' in Article-5 countries and other countries, which would like to convert, has a chance to be informed quickly and consider this technology as early as possible. The HC technology offers advantages on all three levels – global, national, and enterprise.

Global level

The starting point (1990) for the unbelievably rapid development of this technology in Germany and Europe was Greenpeace's position, that only the most environment-friendly technology – HCs – should be used, since HFC134a (hydrofluorocarbon) still has a factor 1200 over the carbon dioxide standard. So it may indeed be only a minor contribution to global warming in total, compared to other carbon dioxide emission sources; it sends a signal for a better ecological solution that became available as with HCs. Unfortunately, the Montreal Protocol is bound to support only the ozone protection in a narrow sense, hence will not pay for the additional positive effect this technology has on global warming. However, this advantage is well recognized in all bodies – the Multilateral Fund and in all implementing agencies – and is getting their support. Although the regulations do not allow extra payment, in a way this global warming contribution is acknowledged in exchange for the extra costs on safety in so far as the costs for safety are not taken into account when compared to other technologies, but will be paid for to a certain degree.

National level

In the past, this technology started with the ecological merits (Greenpeace; no global warming) that convinced the greens everywhere. Last year (1995), the economical advantages became obvious, which will eventually impress the industry everywhere in the world. However, this technology needs a further push now. The most political argument I still find missing so far in worldwide argumentation, in particular with all the queries going on about know-how supply, is that the HC technology leads to independence from western/northern know-how (no patents, no licenses)! This is not only an issue for each company but also for the highest political level in each country, particularly in China and India. This will also apply to Russia and other states being supported by the GEF. Governments seem to have allowed themselves to stay 'neutral' in the economically-based strive for 'synthetic chemicals based technologies' for too long. However, the natural chemicals (HC, ammonia) based technologies support any governments and companies in their attempts to lessen dependence. This technology offers the chance to adapt national 'natural' solutions, instead of being fixed to this little financial support the Multilateral Fund can render. Instead of arguing at length about the money getting more scarce and about the ever-changing rules and regulations, which are, therefore, getting tighter, just go ahead and do it! In this public money game, everybody seems to make a fool of themselves in the long run. These large Article 5 countries do have the means, should they easily pull their policy, people and other resources together and do it! By now it is proven to be simple, everybody can do it. The ever ongoing attempts by the North to keep control and make profits are perfectly matched in this psychology game by the lack of political awareness and technology know-how of the 'dependent' countries. This, to me, looks an 'old' attitude, a basic reluctance to take on responsibility for one's own problems. After all, everybody (!) is using the comfort of cooling, increasingly so after 1987, the year of the Montreal Protocol! So, the time has come for all of us to grow out of this behaviour of the past and start with new thinking. Germany and Switzerland would be willing to assist further in any move for self-help.

Enterprise level

The most promising facts about HC technology, however, are on the enterprise level. The technical advantages will be the driving force!

There are more than five million refrigerators already produced in Germany, Europe, and now in China also, without any reported accident in daily use. Although it was the ecological advantage that got HCs off the ground in the first place, today it is clearly the other advantages with regard to production and daily use that are emerging. These are hard economic facts that will interest the industry. These facts will be the future driving force for HC technology worldwide. Facts like energy-saving, 'whispering' refrigerators, readily available materials, savings in compressor design, virtually no refrigerant losses in production, extraordinary reliability of the cooling system, no fees on licences and patents, and the assurance that no second conversion will be charged on the enterprises in later years will interest any manufacturer worldwide. And that will keep this technology moving on.

Advantages

The 12 advantages in detail as I see them today (there may be many more!) are given below.

1. *No ozone-depletion.* No ozone-depleting effect is the prerequisite of all other chlorofluorocarbon (CFC) substitutes.

2. *No global warming.* No global-warming effect was the starting point of the whole HC movement.

3. *No second conversion.* No second conversion, such as the one hanging over all halogen compounds (e.g. HFC134a), is required in the long run. HFC134a still contains halogens – fluorine instead of chlorine. Fluorine is one of the most reactive of all elements and forms the strongest acid known. Even if all living scientists were to swear that it does not harm the atmosphere, I would feel better if we do not shoot it up there. After all, yesterday's solutions often seem to create today's problems – as did CFCs.

4. *Energy saving.* There is an energy-saving effect with an optimized refrigeration system of up to 10% over CFC and HFC134a. This means a further lifelong contribution to not to accelerate global warming, already a serious selling point in Europe with the newly introduced, compulsory energy labelling.

5. *Quiet refrigerators.* The physical properties of isobutane refrigerators make for quiet, 'whispering' refrigerators, an additional marketing aspect in Europe.

6. *Ready availability.* The HCs – cyclopentane and isobutane – will probably (contrary to, e.g. HFC134a) be readily available in most Article 5 countries and other self-relying countries if there is a definite market for them; they involve no synthetic chemistry, just purification. A realistic approach on purity demands (presently 98% pure; 99% was sought a year ago; future ?%) will further ease the situation.

7. *New compressors self-made.* For companies with their own line of compressor manufacturing, this technology offers at least a possibility – and in most cases it is a real chance – for them to develop new compressors for isobutane or a propane/butane mixture on their own, at relatively low cost, out of their old CFC-compressor modules; whereas HFC134a definitely requires a completely new design. With conversion to HC, there is, in some cases, a slight gain; in most cases, an equal level in energy consumption compared to CFC.

8. *Extraordinary reliability.* The most convincing argument, however, is the reliability of this system, because of fewer compressor failures. The close chemical connection between isobutane and mineral oil means that there is no interfering chemical interaction; in the case of CFC and fluorocarbon compounds, it leads

to corrosion sooner or later and hence to compressor failure, mostly due to moisture from high humidity. But HC compressors run 'forever': test runs show that four million hours can be conservatively expected [80 000 hours (15 years) is the current desired standard and the average lifespan of refrigerators so far]. This high reliability feature was probably the main reason why German industry, impatient with the problems caused by hygroscopic HFC134a oils, converted twice within two years despite the double costs of conversion. This sensitivity towards humidity is, of course, greatly increased in the tropical or subtropical climates of most Article-5 countries. This is why the German manufacturers publicly expressed to the Multilateral Fund their concern that in these countries HFC134a will result in a high failure rate and recommended HC technology for any company with a technical basis for conversion to HCs.

9. *Virtually no refrigerant losses.* The only disadvantage of HCs is their flammability. This requires careful design and thorough employee and service sector training. The European refrigerator industry shows that it can be done. After all, the world has learned to live with a similar open system with gas escaping freely (e.g. cigarette lighter). No one worries about people carrying three cigarette lighters – which is equal to the flammability potential of a household HC refrigerator – in pockets or handbags, where they bounce around a lot more than a kitchen fridge does! Looking at the ozone depleting substance phase-out, the use of HCs may result in a considerable and additional contribution, although it is one of the hidden effects, more in the grey area of a guilty conscience, not openly spoken about since it is embarrassing, none I could find in any official document yet. Due to the danger of flammability, these substances are naturally handled with utmost care. This has the effect that there is virtually no 'losses' in the manufacturing process. On the other hand, manufacturers handling CFCs and HFC134a experience considerable losses in these technological processes. I am told that sometimes the amount purchased is 1.8 times bigger than that which finally leaves the factories in the form of manufactured goods, the rest 80% goes somewhere, likely due to the attitude – 'it is harmless to me'. This leads to the remark of one of the leading German manufacturers, that 'the hydrocarbon technology forces us to work with this care we should always have worked with.'

10. *No extra servicing equipment.* The advantage for using isobutane lies in the service sector and it is another economical benefit. There is no extra servicing equipment necessary for isobutane over CFC, whereas HFC134a requires a completely new system additionally. Handling HCs can be as safe as CFC or HFC134a as far as the danger of accidents due to the flammability is concerned. The situation in Germany proves this. The use of HCs in the servicing sector

offers another contribution to ozone protection, considering the fact that in many countries, particularly in low CFC-consuming countries, by far larger amounts of CFC are used in the service sector and those will be saved. The usage of isobutane and/or blends as refrigerants may open a whole bundle of benefits in the service sector, e.g. due to the required care in handling. For example, using ready-filled cartridges may in the end make not only servicing safer, but also less costly. Dealing with the service sector will be part of GTZ projects in 1996/97, particularly in the area of retrofitting, by which substantial amounts of CFC could be phased out the quiet way.

11. *Technically simple to adopt.* The HC technology is relatively simple to adopt in comparison to 'synthetic chemicals'. Since the same oils and compressor type are used, there is less strain and stress on management and work floor. This offers a whole range of tailor-made adaptations of this technology into the existing situation, which is different in each factory. So, generally speaking, here is a chance for each in-house engineering department to come up with their 'own' solution!

12. *No patents, no licences. no dependence.* What was said about the independence, this technology offers at the national level, and applies, of course, to the company level as well. Here is the chance for any company taking the lead in setting up their own technical development, taking the lead in the market, taking the chance to provide engineering consultancy for other countries as soon as they have been through the process themselves. A good and convincing example is Haier Qingdao. After conversion of one of their factory lines, it now offers co-operation in the introduction of HC technology to any Indian company. In turn, Indian industry may offer this to rest of the world in about one year's time.

The outlook

It is the conviction of people working actively in HC projects that this technology needs another good push now. But soon market forces will keep it running! And that is the best that can be hoped for any ecologically well-based technology. My plea to you is: help to keep the HC domino running in the right direction! Thanks.

Energy-saving design of no-pollution refrigerators – application of hydrocarbons on refrigerators

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Introduction

In China, there are more than 40 refrigerator/freezer manufacturers. Haier Group is the first Chinese manufacturer that has carried on the work of CFC11 and CFC12 substitution; it has obtained many interim optimum achievements as well. Annually, about eight million refrigerators/freezers are made in China, consuming large amounts of ozone depleting substance (ODS).

Table 1. Methods of substitutions

CFCs	Substitutes
R12	R22/R152a blend, R134a, and R600a
R11	50% CFC11, R141b, and cyclopentane

All the substitutes shown in Table 1 are being studied. As a model factory of Chinese Government Environment Protection Bureau, China Light Industrial Council, US Environment Protection Agency, German Agency for Technical Co-operation, and Leibherr, Haier enforces international technology cooperation, and does lot of research about various substances for the foaming agent and refrigerant including substitutes recommended by the Montreal Protocol fund, taking special situations of China into consideration. All these substitutions have been realized in the mass production at Haier.

In December 1994, one of its production lines was altered to cyclopentane foaming, and its assembly line was changed to production using R600a (isobutane) as refrigerant and gained the safety certification of TÜV (Energie und Umwelt). Its new model BCD-268 refrigerator has realized zero pollution to the environment, with increased energy-saving capability (50%), which exceeds the class A of 'European energy consumption regulation'. This is the first refrigerator that has adopted HCs as the substitute in China. It also reduces the pollution caused by electricity generation.

Cyclopentane as a foaming agent

Some production control parameters of cyclopentane foaming are given below.

- Purity of cyclopentane more than 70%
- Explosion-proof safety system
- Mould temperature controlled between 40 and 50 °C
- Ratio of foaming agents – polyol:isocyanate = 445:543
- Density range of foam is 36–40 kg/m^3
- String time controlled between 45 and 55 seconds

Specialties of cyclopentane-foamed cabinet as compared to normal 50% CFC-foamed cabinet are given below. From Table 2, it can be seen that cyclopentane-foaming is feasible in factory. Safety problems can be solved by altering the production line. In cyclopentane foaming, there will be a five to eight per cent increase in energy consumption. Therefore, refrigerators must be subjected to energy-saving design after CFC is substituted by cyclopentane.

Table 2. Comparison of cyclopentane-foamed cabinet and normal 50% CFC-foamed cabinet

	Foam systems	
Items	*Low freon (50% CFC)*	*Cyclopentane*
Average density (kg/m^3)	34.6	39.3
Compressing strength (kpa)	>134	>160
Heat conductivity (MW/mk)	18.4	20.4
Stability of dimension (−30 °C × 168 h)	<0.5%	<0.3%

Refrigeration system adopting isobutane as refrigerant

Tables 3–5 show that adopting isobutane as refrigerant is better in terms of efficiency than using R134a because of the compressor and other factors.

Analysis of results

Besides high-freezing capacity and zero pollution to the environment, isobutane has a high energy saving potential. It achieves the European energy consumption

Table 3. Comparison of properties of isobutane (HC600a), CFC12, and R134a

Refrigerant	Ignition temperature [°F (°C)]	Normal boiling temperature [°F (°C)]	Flammable limits [per cent by volume in air (lower/upper)]	ODS/ GWP*
HC600a	860 (460)	11 (–12)	1.8/8.4	0/3
CFC12	Non-flammable	–21.6 (–29.8)	Non-flammable	1.0/7100
HFC134a	Non-flammable	–15.1 (–26.2)	Non-flammable	0/3200

*Ozone depleting substance/global warming potential (GWP compared to CO_2)

Table 4. Designing a refrigerator using isobutane as refrigerant

Climate class	N
Star mark	* * * *
Volume	Refrigerator 160 litre/freezer 108 litre
Thickness of foam	Freezer 100 mm, refrigerator 60 mm
Foaming agent	Cyclopentane
Compressor (Americold)	HC82, capacity 130 W coefficient of performance (COP) 1.4 (w/w)
Isobutane	65 g
Control system	Two-way circulation by using solenoid valve and temperature controlled separately
Dry filter	XH - 5
Flow rate of capillary tube	Adjust appropriately
Evaporator of refrigerator	Hidden between inner liner and foam layer
Evaporator of freezer	Plate-tube type, positioned as layers in the cabinet
Condenser	Area: 580 x 1040 mm
Model	BCD-268

Table 5. Results of performance test as per test standard ISO 8187

Parameter	Test results
Energy consumption	0.70 kWh/24 h
Freezing capacity	20 kg/24 h
Temperature rise time	1800 min (−18 °C → −9 °C)
Noise	39 dB
Storage temperature	N 32 °C, 16 °C qualified

potential: I = 45.31%. It has exceeded the class A of 'European energy consumption regulation' (For class A, I <55%)

Energy-saving design

Insulation layer thickening

The most direct method to save energy is to thicken the thermal insulation layer so as to reduce the coldness leakage. Energy-saving can reach up to 30% by this way.

High-efficiency compressor

Adoption of high-efficiency compressor can save energy directly. Higher the COP of compressor, more effective it is in energy-saving. By using Americold HC82 compressor (COP = 1.4), the energy saving increases by 15% compared an ordinary compressor.

The optimum design of refrigeration system

Reasonable enlargement of condensing area

The condensing area of BCD-268 is larger by 20% in comparison to an ordinary one. This can reduce the discharge pressure and increase the degree of over-cooling.

Suitable area of evaporators

The area of the evaporator of refrigerator should be designed appropriately to meet the temperatures of fresh food compartment (5 °C) and freezer (−18 °C). Energy consumption can be reduced by 5%–10% this way. Too small or too large a refrigerator evaporator can cause an increase in energy consumption.

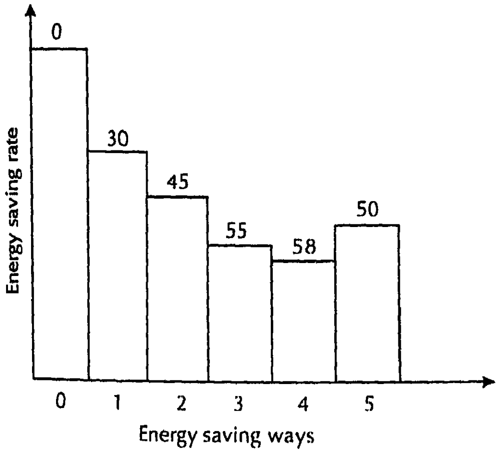
Optimizing on/off time

The time rate of the compressor can be controlled by selecting suitable on/off temperature of the thermostat (on time rate = on time or on time + off time). If the compressor cycle time is short, the energy consumption will be high because of the high start-power. If the working time is too long, the compressor will always work under low temperature of evaporation. In this case, the compressor's COP is the lowest and the energy consumption will increase. Every system has an optimum range of working time, in which the refrigerators work most economically. By choosing a reasonable on/off time through experiments, refrigerators can save energy up to four to six per cent.

Change in the construction of door gasket

The design of door gasket should prevent cold air from contacting the metal enclosure, increase the number of gas rooms, and reduce the thickness of door gasket to reduce coldness distribution area. A reasonable design can save energy by about three per cent.

The energy saving proportion of the methods mentioned above is shown in (Figure 1).



0 – No energy-saving ways adopted; 1 – Thermal insulation thickening;
2 – High COP compressor; 3 – Improve refrigeration system;
4 – Adopt good gasket; 5 – Adopt cyclopentane foam.

Figure 1. The energy saving proportion of different methods

Conclusions

Refrigerators using HCs as foaming agent and refrigerant will give good performance in terms of refrigeration and energy saving. Safety measures will have to be adopted in HC refrigerator production to avoid accidents. From the various experiments with CFC-substitutes carried by Haier, HC has been found to be an optimum substitute as far as environment protection and energy saving are concerned.

Eco-refrigeration: an overview of hydrocarbon technology in India

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Ecofrig project

The Ecofrig project was initiated with an exploratory visit by Infras AG/Dasag Swiss mission to India sponsored by Swiss Agency for Development and Cooperation (SDC) in September 1992 while the concept of hydrocarbon (HC) refrigerator was still at its infancy. The mission identified the scope for an Indo-Swiss joint project with some Indian refrigerator manufacturers (Godrej - GE Appliances Ltd, Kelvinator of India, Voltas Ltd) and research institutions [Indian Institute of Technology (IIT), Delhi; National Chemical Laboratory (NCL), Pune]. This was followed by the visit of an Indian delegation to Switzerland and Germany, and later by a Swiss/German delegation to India in 1993. The Indian delegation was shown how refrigerators were manufactured with propane–isobutane mixtures by Foron/DDK Scharfenstein in Niederschmiedeberg, Germany. This visit gave enough confidence to the Indian delegation for further collaboration. A short-term project was defined to carry out a pre-feasibility study on the suitability of HC refrigerators under Indian conditions. This study was carried out by IIT, New Delhi and NCL, Pune in close cooperation with some of the domestic refrigerator manufacturers (Agarwal *et al.* 1993). The results were encouraging and a further study was undertaken.

A technical workshop was organized in March 1994 at IIT, Delhi in collaboration with FKW, Hannover, where most of the Indian domestic refrigerator manufacturers participated. During the workshop, IIT successfully converted and tested some Indian refrigerators with propane–isobutane mixture (Agarwal *et al.* 1994; Devotta, Agarwal 1994). It was realized that there was a substantial scope for HC technology in India.

Further, collaborative research efforts continued at research institutions and in the R & D laboratories of the industry. Foron and FKW were the collaborating partners from Germany. The German government also partially supported the joint project. A few Indian refrigerators were also tested with propane–isobutane mixture under retrofitting conditions with minor modifications made at Foron and by Indian enterprises. The performance characteristics of these refrigerators were almost similar to those with CFC12 (chlorofluorocarbon). The use of this mixture also meant no change in lubricating oil and in compressor except an increase in capillary length. In comparison, the leading German refrigerator manufacturers introduced isobutane-based refrigerators in Europe. Isobutane was preferred over mixtures of propane and isobutane due to a single component refrigerant, slightly better energy efficiency, and low noise of the compressor.

In view of this development, further studies were undertaken by research institutions to design, develop, and evaluate the performance of domestic refrigerators based on isobutane and isobutane–propane mixtures. The same have also been extended to commercial refrigeration appliances. NCL, Pune has been studying the issues related to the availability of HCs, lubricants, and the Indian and international standards for safety of such appliances. The present phase of the project also studies the various aspects including safety issues during servicing of HC-based domestic refrigerators and commercial refrigeration appliances.

The Tata Energy Research Institute (TERI), in association with IIT, Delhi, studied the levels of energy consumption in domestic refrigerators of different brands in actual field conditions for all the seasons in various parts of the country. The test results were compared with that of laboratory-tested.

Some of the domestic refrigerator manufacturers have considered cyclopentane, a foam-blowing agent, as an alternative to CFC11. The cyclopentane polyurethane foam technology will be demonstrated under the Ecofrig project at the premises of two enterprises. Recently, a formal agreement between the governments of Switzerland, Germany, and India and some of the industries has also been signed for the demonstration project for cyclopentane foam-blowing.

Status of hydrocarbon technology in India

Hydrocarbon technology (both foam-blowing and as refrigerant) is being evaluated extensively. Some of the domestic refrigerator manufacturers are actively considering cyclopentane and isobutane as potential alternatives to CFC11 and CFC12, respectively. The research institutions are closely associated in the process of evaluation along with some German research institutions and industries.

Hydrocarbon refrigerants

Hydrocarbon refrigerants have zero ozone-depleting potential (ODP) and a negligible global warming potential (GWP) (Table 1). Their efficiency is slightly better than other leading alternative refrigerants and they are fully compatible with lubricating oils conventionally used with CFC12. The latent heat of vapourization of HC refrigerants is very much higher in comparison to CFC12 and its density is approximately one-third of CFC12 making these refrigerants attractive because of its low charge requirements and circulation rates.

In Europe, HC refrigerants have successfully been introduced in domestic refrigerator-freezers. Almost all the major domestic refrigeration appliance manufacturers in Germany have converted the manufacturing facilities to isobutane as refrigerants and cyclopentane as foam-blowing agents.

Table 2 presents the calculated relative performance parameters for propane–isobutane mixture, pure isobutane, and HFC134a as leading alternative refrigerants to CFC12 for a theoretical cycle having a –25 °C evaporator and a +55 °C condenser.

Table 1. Alternative refrigerants to CFC12 for domestic and commercial refrigeration appliances

	Refrigerant			
Parameters	*CFC12*	*HFC134a*	*HC290/600a*	*HC600a*
Formula	CF_2C_{l2}	CH_2FCF_3	C_3H_8/C_4H_{10}	C_4H_{10}
Molecular weight	120.93	102.03	51.12	58.13
Critical temperature (°C)	112.0	101.1	96.0	135.0
Boiling point (100 kPa)	–29.8 °C	–26.16 °C	–30 °C	–11.73 °C
Density (kg/m^3; –25 °C)				
Saturated vapour	7.57	5.50	3.14	1.66
Saturated liquid	1472.0	1371.0	584.4	608.3
Flammable limits (% in air; 20 °C; 100 kPa)	None	None	1.8–9.0	1.4–8.4
Threshold limit values/OEL	1000	1000	1000	1000
ODP	1.0	0	0	0
GWP	3.1	0.27	<0.01	<0.01

Table 2. Comparative performance indices for leading refrigerants for domestic refrigerator

	Refrigerant			
Parameter	*CFC12*	*HFC134a*	*HC290/600a*	*HC600a*
Formula	CF_2C_{l2}	CH_2FCF_3	C_3H_8/C_4H_{10}	C_4H_{10}
Volume capacity (kJ/m^3; −25 °C)	1237	1185	1254	626
Pressure ratio (−25 °C/+55 °C) subject to 32 °C	11.03	14.07	11.42	13.39
Coefficient of performance, theoretical (−25 °C/+55 °C) subject to 32 °C	Equal to HFC134a	—	less than/ equal to HFC134a	more than HFC134a
Discharge temperature, theoretical	120–125	115–120	105–110	100–105
(−25 °C/+55 °C) + suction gas cooling (practical)	170–175	150–155	140–145	135–140

Evaluation of hydrocarbon technology

The performance of both, propane–isobutane mixture and isobutane individually, has been evaluated at IIT, Delhi for domestic as well as for commercial refrigeration appliances. This section presents some of the results of these studies.

Propane–isobutane mixture based appliances

The propane–isobutane mixture can be used with compressors designed for CFC12. The binary mixture ratio can be conceivably designed using boiling point as a guideline such that the design requirements of the freezer and the fresh food compartment in domestic refrigerators can be balanced. The normal boiling temperature for R290/R600a mixture (each 50% by mass) ranges from −32 °C to −24 °C, which is very close to normal boiling point of CFC12, the current refrigerant. The mixture, in comparison to CFC12, possesses very high latent heat of vapourization and low value of density (one-third of CFC12), which makes the mixture attractive due to its low charge requirement and circulation rates. The charge levels are approximately 40% that of CFC12. One of the major advantages of R600a/R290 blend is its compatibility with mineral oils and commonly-used materials for manufacturing refrigeration systems with minimal changes required in the refrigerant system.

A number of Indian domestic refrigerators have been modified by adjusting the capillary length desired for propane–isobutane mixture. The performance of these refrigerators as per BIS 1476 has been evaluated and compared with that of CFC12 (Agarwal *et al.* 1994a; 1995; 1995a). However, it was seen that with proper optimization of capillary length and amount of refrigerant charge, the performance level increases. There is almost no energy penalty. The quantity of charge required is only 45 g in comparison to 90 g of CFC12 (Agarwal *et al.* 1995b). The mixtures can be treated almost as a drop-in substitute. Refrigerators that are converted to propane–isobutane mixture are in normal operation for the past two years.

At present, a number of commercial refrigeration appliances, namely, visicoolers of various capacities and horizontal bottle coolers, have also been converted to operate on propane–isobutane mixture. The performance of these appliances is also almost similar to CFC12 if length of capillary and amount of charge are optimized. These appliances have been in operation for the past six months.

Isobutane-based appliances

Isobutane is a single component HC refrigerant with a normal boiling point of –11.85 °C. This refrigerant, in spite of having sub-atmospheric pressure at suction, has been widely considered as one of the practical solutions for small capacity refrigeration appliances such as domestic refrigerator-freezers, visicoolers, deep freezers, chest freezers, and water coolers. At IIT, Delhi, a long-term programme has been taken up to assess the potential of isobutane as an alternative refrigerant under Indian conditions.

In the first phase of the study, an isobutane compressor was designed and developed using the existing Indian compressors suited to 165-litre domestic refrigerators. Subsequently, an Indian 165-litre refrigerator was modified to operate on isobutane refrigerant in April 1995. Then, the capillary length and the amount of refrigerant charge were optimized to achieve energy efficiency. The performance of modified refrigerators was almost the same as that of CFC12 (Agarwal *et al.* 1995). The performance of compressors developed by domestic refrigerator manufacturers has been evaluated. The study revealed that isobutane technology does not require any change in the manufacturing process except for safety precautions. A similar approach has also been adopted for commercial refrigeration appliances.

Servicing of hydrocarbon appliances

Hydrocarbon refrigerants are free from halogen elements, compatible with mineral oils and do not have chemical reaction with the commonly-used materials in manufacturing and servicing of refrigeration appliances. Thus the servicing of HC appliances would not require any substantial change. Isobutane and mixture of propane and isobutane compressors can be serviced including the valve plates, motor winding, etc., as per the existing practice for CFC12 compressors in India. However, due care should be taken during charging of refrigerant, i.e. avoidance of ignition source.

Comparative study of isobutane and HFC134a technologies

Table 3 presents a comparative study of HFC134a and isobutane–propane and isobutane technologies from the point of view of manufacturing and servicing.

Safety standards and regulations for manufacturers of hydrocarbon appliances in India

A detailed study has been undertaken by NCL, Pune to look into various aspects of safety issues while adopting HC technology in India. The study has outlined the

Table 3. Comparison of HFC134a and HC technologies

HFC134a	HC
Lower system efficiency	Higher system efficiency.
Deep change in compressor manufacturing processes	No change in compressor manufacturing processes
Highly sensitive to moisture content	Negligible sensitivity in moisture content
High degree of cleanliness for the whole refrigeration system	Prevalent order of cleanliness is acceptable
Higher potential of system malfunction due to accidental pollution	Negligible effect
Relatively higher noise level	Low noise level with isobutane as refrigerant
Non-flammable	Flammable
Higher cost of refrigerant and lubricant	Low cost
Essential to upgrade servicing practice	Existing service practice may be followed with safety precautions
No safety measures are required	Safety measures are required

measures to be considered in various stages such as storage, manufacturing, use of HC appliance and servicing (Devotta 1995). It has also been suggested to adopt safety guidelines, which are available in some of the other countries like Germany.

Energy consumption of Indian domestic refrigerators under field and laboratory conditions

The Tata Energy Research Institute – in collaboration with IIT, Delhi – conducted an exhaustive study under Ecofrig project for measuring energy consumption in the field and laboratory conditions (Agarwal *et al.* 1995b). During this study, average energy consumption of Indian refrigerators was measured under field and laboratory conditions (as per Indian Standards 1476) in four climatic zones covering different regions of India. One hundred and fifty five households were surveyed for three brands of 165-litre refrigerators. The main objective of the study was to establish a baseline of energy consumption level in such appliances under field conditions.

Conclusions

Based on the studies carried out and the experience gained by research institutions and the collaborating Indian domestic refrigerator manufacturers, by way of interaction and visits to the manufacturing facilities of HC-based appliances in developed countries, the conclusions drawn are given below.

- HC technology is a promising and proven technology for domestic and commercial refrigeration appliances.
- It does not require any change in the process of manufacturing of compressor, appliances, and other components used in these appliances.
- The safety issues, arising out of the flammable nature of refrigerant, need due considerations. The amount of charge is so small that safety issues can be taken care of with the present level of technical know-how.
- The existing service practices, especially the repairing of hermetically-sealed compressors, would not require any major change except training of technicians for handling of flammable refrigerants.

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Eco-refrigeration: highlights from India

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Introduction

The Ecofrig project between Swiss Agency for Development and Cooperation (SDC) and Indian industries had its origin in September 1992 when Dr Othmar Schwank of Infras AG (a Swiss Environment Consultancy) along with Dr Hari Sharan of Dasag Ltd (a Swiss Energy Engineering Consultancy) called a meeting (on behalf of the SDC) in Mumbai regarding the use of hydrocarbon (HC) fluids in domestic refrigeration. Although the Indian industry had hardly ever known of HCs being used as refrigerants or as insulation foam-blowing agents, two Indian companies (refrigerator manufacturers) and two national R & D institutions agreed to participate in the project purely from an R & D perspective.

From scepticism to belief

The SDC, through Infras AG, arranged for two visits of Indian industry to Europe – one in 1993 and the other in 1994. These visits removed much of the initial scepticism that the industry had on the use of HCs on a large scale. The visit in 1993 enabled Indian companies to see the transformation that had just begun in Germany owing to the use of HCs as refrigerants and as foam-blowing agents. Foron GmbH, an East German Company, had spearheaded the change, using HC mixtures as refrigerants.

Workshops were conducted at the Indian Institute of Technology (IIT), Delhi in February 1994 with faculty from FKW (Institution of Refrigeration), Hannover, where R & D institutions and four Indian refrigerator manufacturers participated.

The project *inter alia* included 'refrigerator testing', and three Indian companies sent their refrigerators to Foron for testing with HC mixtures as 'refrigerants'. In addition, the Indian partners were also provided with samples of HC mixtures to carry out their own trials in their laboratories.

Transformation in Germany – the HC reality

Three Indian refrigerator manufacturers, during their 1994 Europe visit, visited Liebherr, AEG Hausgerate GmbH, and Foron (German refrigerator manufacturers) and attended the Hannover International Conference on 'Natural Fluids and Hydrocarbons'. This visit confirmed the reality of the use of HC as a refrigerant and also as a foam-blowing agent. German manufacturers, who had first used synthetic fluids like HFC134a as refrigerant and halogen-based foam-blowing agents, had switched over to isobutane as refrigerant and cyclopentane as blowing agent. A visit to the independent German Safety Agency – TUV Energie und Umwelt GmbH – gave an insight into the stringent safety measures insisted on by TUV while certifying the installations using HCs. The results of the tests conducted on the Indian refrigerators at Foron were discussed and analysed.

The most important outcome of this visit was the 'cooperative understanding' entered into between two Indian refrigerator manufacturers and the SDC for the setting up of a 'Pilot Cyclopentane Foam Blowing Plant' at their factories on an equal cost-sharing basis. To a great extent, this was facilitated by the two senior officials of Government of India who were present at the meeting in Germany when the decision was taken. This exercise would enable the participating Indian companies to gain a first-hand experience in the handling of cyclopentane and in carrying out adaptive research and application engineering, leading to pilot production. The understanding also included plans for studying the possible use of HCs as refrigerants in India.

Action phase (1995)

The understanding arrived at was then formalized through the Indo-Swiss government-to-government agreement and the memorandum of understanding signed by the industry partners, Infras AG (on behalf of SDC), and the Ministry of Environment and Forests, Government of India.

Other agreements were also signed by:

- industry partners, Infras AG, and FKW (Research Centre for Refrigeration Technology and Heat Pumps Ltd), Germany – for carrying out life testing of Indian compressors using CFC12 (chlorofluorocarbon), HC mixtures, and isobutane.
- industry partners, Infras AG and DKK (Agency for Development and Project Management), Germany – for carrying out calorimetric testing of Indian prototype of compressors, using isobutane.
- Afros Cannon, Italy and Plasttechnik Greiz, Germany Consortium; industry partners; and Infras AG for supplying the foaming machine with one set of fixtures for cabinet and door for the use of cyclopentane as a blowing agent.
- Infras AG, Liebherr (Germany), and industry partners for studying the changes needed in direct-cooled and frost-free Indian refrigerators for using isobutane as a refrigerant.

While the calorimetric tests have been completed, life-testing is almost coming to a close. The consignment of foaming plant and equipment is scheduled for despatch from Europe by the end of January/early February (1996).

Results

The objective of this cooperative project was to introduce and familiarize the Indian industry with the use and advantages of HCs in lieu of synthetic chemical fluids. The flammability and safety precautions needed while handling HCs have also received special attention and care. With the commissioning of the pilot foaming plant, the Indian manufacturers will get first-hand experience on the use of HCs at the plant level and in the safety measures that are needed for handling cyclopentane. This should give the industry the necessary confidence in the care and precautions to be taken while handling flammable and explosive fluids. Cyclopentane, as a blowing agent, ranks high as a first choice for the Indian industry partners. Regarding HCs, as refrigerants, the pros and cons of their use are being studied, weighed, and debated and the results of the sub-project above should go a long way in shaping the decision.

A unique project

The project has been a unique cooperation exercise. It has brought together industry competitors, national research institutions, three governments (Swiss, German, and Indian), and German and Italian industry – all working harmoniously and cooperatively. A special mention has to be made on the role of Infras AG (acting on behalf of the SDC), who have acted as live-wire project coordinators and implementors and who have brought these projects to such an advanced stage.

Acknowledgements

The industry partners wish to acknowledge and thank the following organizations for their unstinted help and cooperation:

- SDC and Infras AG
- GTZ and German industries (Foron, Liebherr, and FKW)
- Cannon, Italy
- PTG, Germany
- TUV, Germany
- Ministry of Environment and Forests (Government of India)
- Indian R & D institutions (IIT, Delhi; NCL, Pune; and Tata Energy Research Institute, New Delhi).

New global initiatives

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Dear colleagues, friends, ladies and gentlemen. Good afternoon.

I wish to thank the conference organizers for having extended an invitation to the World Bank. We are delighted to be here. I would like to congratulate the Government of India, the Government of Switzerland, and the Government of Germany on their pro-active approach to pursuing this environment friendly technology. I would also like to extend my congratulations to the Indian industry on their interest in the state of their technology. Earlier on, Ambassador Ducrey mentioned that the World Bank was listening. I am pleased to tell you that we are doing more than just listening; we are taking action. But taking action in isolation would be foolish as there are too many stakeholders in this evolving business. The Bank's experience and that of other agencies, whether multilateral or bilateral, is that there remains some barriers to the further spread of hydrocarbon (HC) technologies. And if we are to capitalize on all the environmental benefits of HC refrigerators (zero ozone depleting potential, negligible global warming potential, higher energy efficiency among others), we must develop a better understanding of these barriers and how they can be addressed.

Why is that there are only seven per cent of global compressors manufactured last year (1995) were based on HC technology. This is the question we need to answer. Therefore, the World Bank, with German Agency for Technical Cooperation (GTZ), Swiss Agency for Development and Cooperation, and Infras, has undertaken the task to assess the prospects of HC technology in the global domestic refrigeration market.

This assessment will be comprised of three distinct sub-studies: technology survey; market survey; and barrier study. The overall study will also closely examine a limited number of case studies including the experience of India in its efforts to try and assess the suitability of HC technology, the experience of China, Argentina among others. The cornerstone of this study is the barrier study. The learning process, which began three years ago here in India when the Ecofrig project was inaugurated, would be most critical in the overall global assessments.

The findings of these three sub-studies and of the overall study will be considered by a select group of stakeholders at a workshop to be hosted by the Swiss Government in Switzerland next May. The findings and the proposed action plans will be publicized this year (1996) in the form of papers in a series of international conferences. This study will be managed and coordinated by the London-based consulting firm, Touche Ross, and we have a representative of this firm with us for this conference.

Finally, let me wish all of you a very successful workshop. To my colleagues in the Indian industry, please avail yourself of this exceptional opportunity to adopt state-of-the-art technology. The final decision is in your hands. Although the funds from the Multilateral Fund may be limited, they are nevertheless available. And, I think that this decision to move ahead must be above and foremost a business decision. I hope you now have, should now have, all the incentives to support your decision to convert to ozone depleting substance-free technologies and also hope that this conference would allow you to get the final answer that you are seeking on technical issues. Do not be left behind. The global technology is changing and the competitiveness of your industry on a global scale is at stake.

Thank you.

SESSION II

SYNTHETIC AND NATURAL FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION

CFC substitutes (R600a and R134a): performance, manufacturing, and costs from the compressor point of view

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Theoretical performance

The theoretical comparison of the performance of different refrigerants, including blends, requires the definition of a tested method. In the case of non-azeotropic blends, it is not perfectly identified. The different characteristics of the blend components can give incomplete isothermal state transition paths and this temperature glide can cause some vagueness in the test conditions.

The theoretical cycles have the vapour over-heating and liquid sub-cooling temperature coincident and set at 32 °C. The condensing temperature is 55 °C and the main comparisons are at −23.3 and −30 °C.

In Figure 1, ideal reference cycle for performance calculations is shown. In Figures 2–4, performances of R12 and a hydrocarbon (HC) blend are compared. The X-axis is the R290 percentage. Chart 1 shows the main characteristics numerically to allow some considerations.

Considerations

Suction pressure

Suction pressure is almost similar for R12, R134a, and R290/600a blend; it is much below the atmospheric pressure for R600a, particularly for low evaporating pressures. This makes the gas leakage on the suction side of the circuit more critical as air ingress is possible, and system pollution is a consequence.

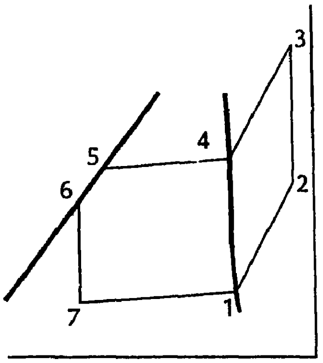

Figure 1. Ideal reference cycle for performance calculations

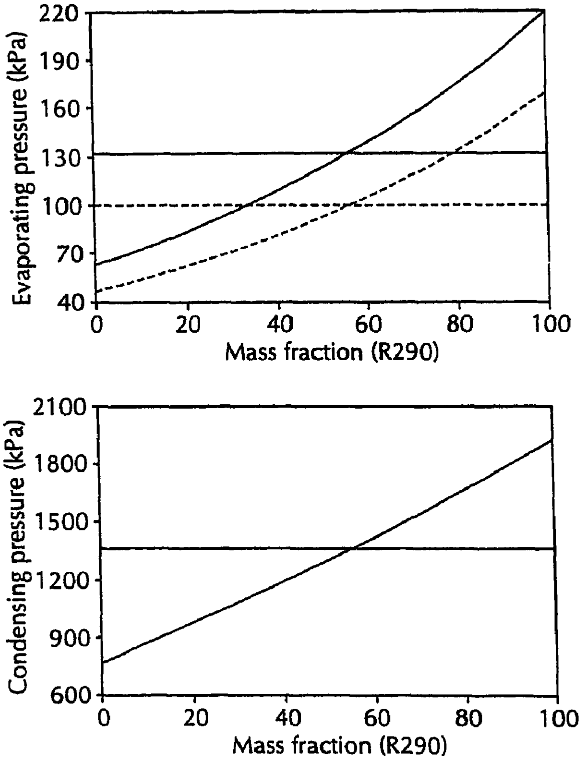

Figure 2. Evaporating and condensing pressure of R290/600a blend in ideal cycles with 55 °C condensing temperature and −23.3 °C (——) and −30 °C (------) evaporating temperature. The straight line is related to R12

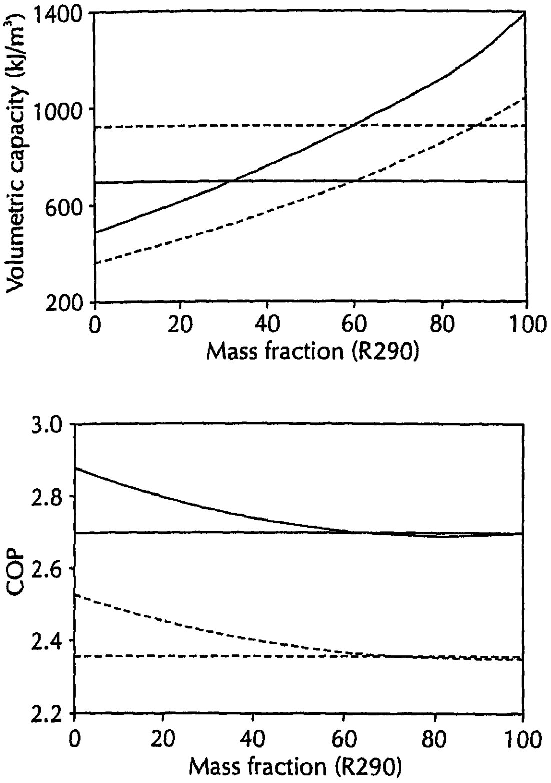

Figure 3. Cooling capacity and efficiency (COP)

Discharge pressure

Discharge pressure is also similar for the three above-mentioned refrigerants, but it is approximately half for R600a. This will produce less stress and pulsations of the gas in the discharge side with potentially lower noise.[1]

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[1] Common sense would make one think that noise reduction can come as a direct consequence of lower discharge pressure, but this is not always true. The acoustical impedance of a gas is directly proportional to the density, and the density of R600a is much lower than the other refrigerants under any operating conditions. For this reason, the noise reduction can become actual, but only after a fine tuning of the internal components of the compressor affecting the acoustical radiation, particularly on the suction side, where the gas pulsations involve a wide surface and, therefore, a high sound power.

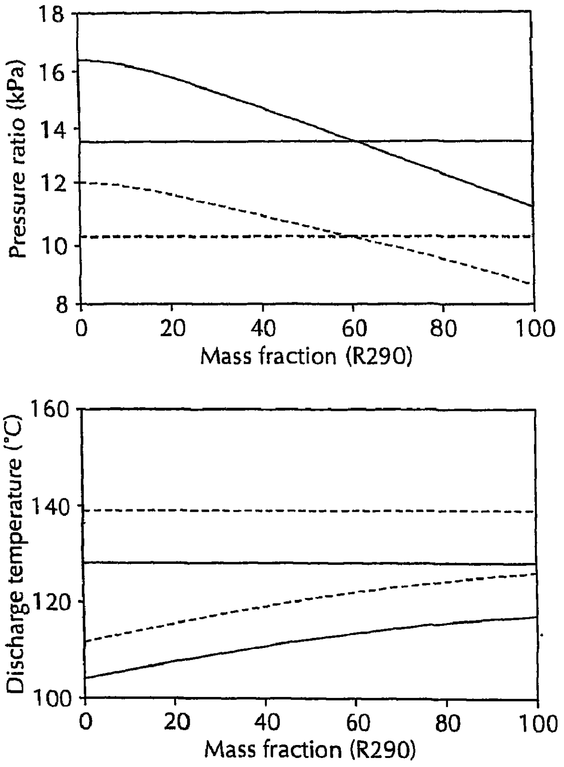

Figure 4. Compressor discharge pressure ratio in comparison to R12

Specific volumetric capacity

Specific volumetric capacity of R600a is only half when compared to other alternatives. As a consequence, keeping constant the cooling power of the system, the displacement of the compressor must be increased.

Compressor manufacturers have been using all the design techniques to reduce this displacement increase as much as possible. Improvement of volumetric efficiency, reduction of gas temperature to increase its density at the suction, etc. have been applied and, in general, the displacement increase has been limited to 70%–80%.

Theoretical efficiency

The theoretical efficiency of R600a is higher than others and the related impact on the global warming potential (GWP) is smaller. The actual efficiency must be

Chart 1: Theoretical performance of R12 substitutes

Temperature	Major characteristics	Unit	R12	R134a	R600a	R290/ 600a (50:50)
50 °C (Condensing temperature)	Discharge pressure (p_5)	kPa	1364.00	1495.00	772.20	1296.70
	Liquid enthalpy (h_6)	kJ/kg	230.70	244.00	275.00	279.00
	• Condenser ($t_4 - t_5$)	°C	0.00	0.00	0.00	6.43
–30 °C (Evaporating temperature)	Suction pressure (p_2)	kPa	100.10	84.28	46.95	91.30
	Compression ratio (p)	—	13.63	17.74	16.45	14.20
	Suction density (d_2)	kg/m^3	4.86	3.44	1.09	1.83
	• Evaporator ($t_1 - t_7$)	°C	0.00	0.00	0.00	5.78
	Refrigerating capacity ($h_2 - h_7$)	kJ/kg	144.10	187.70	334.60	346.00
	Volumetric capacity ($d_2 \times h_2 - h_7$)	kJ/m^3	700.50	645.70	364.40	635.60
	Compressor discharge temperature (t_3)	°C	139.10	129.55	111.19	120.72
	Theoretical COP (COP)	—	2.40	2.39	2.53	2.39
–23.3 °C (Evaporating temperature)	Suction pressure (p_2)	kPa	132.00	114.60	63.20	121.20
	Compression ratio (p)	—	10.30	13.10	12.22	10.70
	Suction density (d_2)	kg/m^3	6.50	4.70	1.47	2.45
	• Evaporator ($t_1 - t_7$)	°C	0.00	0.00	0.00	5.58
	Refrigerating capacity ($h_2 - h_7$)	kJ/kg	143.07	187.30	334.00	345.00
	Volumetric capacity ($d_2 \times h_2 - h_7$)	kJ/m^3	926.90	880.90	491.30	846.60
	Compressor discharge temperature (t_3)	°C	128.30	120.09	103.47	112.33
	Theoretical COP (COP)	—	2.70	2.73	2.79	2.73

checked because the normal life-cycle of a refrigerator is determined by a continuous alternance of non steady-state situations and that is significantly different from the theory.

Working parameters

Working parameters of the R290/600a (50:50) blend are similar to R12 or R134a. However, an optimal condition would be at 60:40 ratio.

Application

The comparison is made at two levels. First is at the level of compressor tested on the calorimeter. This will allow some considerations coming from the actual behaviour of the compressor. The second is on the application level giving the idea of changes required for the tuning of ecological compressors on the appliance.

Compressor tests

The comparison at the compressor level is reported in Table 1, which includes the cooling capacity and COP evaluations on a typical compressor produced in large

Table 1. Global performance comparison of R600a and R134a

	R600a		
Model	*Displacement (cc)*	*Cooling capacity (kcal/h)*	*Energy efficiency ratio (w/w)*
HGTR4.5	4.7	60	0.99/1.10
HGTR5.5	5.5	74	1.05/1.16
HGTR6.5	6.5	86	1.10/1.70
HGTR8	8.2	109	1.12/1.21
HGSR9	9.1	122	1.23/1.34
HGSR11	10.6	140	1.28/1.39
HGSR13	12.5	160	1.30/1.41
HGSR15	15.1	203	1.29/1.40

	R134a		
Model	*Displacement (cc)*	*Cooling capacity (kcal/h)*	*Energy efficiency ratio (w/w)*
ETR3.5	3.50	65	0.93
ETR4	4.10	75	0.98
ETR5	5.12	101	1.07
ETR5.5	5.55	112	1.10
ESR7	7.00	127	1.16
ESR8	7.75	148	1.15
ESR8.5	8.20	160	1.17
ESR11	10.60	212	1.15

volumes (5.5 cc tested with the different refrigerants and, in the case of high efficiency version, with the run capacitor).

Cooling capacity

The confirmation of theoretical data is evident. The R134a application is producing slightly lower capacity than R12. The cooling capacity of R600a is approximately 50% in all the evaporating temperature range and this is confirming the need to increase the displacement of the compressor to get the same performance on any appliance. The point to be noted is that the R290/600a blend also has similar capacity as that of R12.

Coefficient of performance

The improvement obtained with the blend using the run capacitor is significantly higher than expected. The run capacitor usually gives 8%–10% increase in efficiency. The high value measured has been interpreted as a positive 'side-effect' of the general temperature decrease inside the compressor. This seems to give higher benefit with HCs than with other refrigerants. However, this statement has not been investigated further. R600a is showing better values than R134a and is also consistent with theoretical calculations.

When compared horizontally, the compressors of the two series had the same overall dimensions.

Fridge/freezers tests

The synthesis of some tests carried out on refrigerators of various kinds is reported in Table 2. The main objectives are given below.

- To identify the behaviour of refrigerators with only the gas charge and the compressor change (In none of the tests, the heat exchanger was modified.)
- To check some of the applications from the retrofit point of view

Considerations on the refrigerator behaviour

- The use of R600a has confirmed the need for compressors with a significant increase in displacement; but the rate of increase is smaller than expected looking at the theoretical data. The reasons are listed below.
  - Actual temperatures of compressors along the thermostat cycles with R600a (and HC blend also) were lower than the ones considered for theoretical calculations. Therefore, the gas density and the consequent volumetric efficiency of compressors were better. This aspect is amplified with the use of the run capacitor.

Table 2a. Single door refrigerator

	Nominal volume (litre)									
	140		*170*		*190*			*140*		
Parameter	R12	R600a	R12	R600a	R12	R134a	R600a	R12	R134a	R290/600a
Charge (g)	110	40	120	58	75	73	27	80	87	25
Compressor type (cc)	4	6.5	4	6	3	3	4.5	4	4	4
Fridge temperature (°C)	5	5	5	5	5	5	5	5	5	5
Freezing temperature (°C)	−18	−17.5	−9.4	−8.7	—	—	—	−8.3	−9.1	−8.5
Energy conservation (kWh/24 h)	1.12	1.07	1.16	1.06	1.09	0.93	0.87	1.14	1.13	1.08
Running %	47	51	43	42	52	47	48	37	40	43

Table 2b. Double door fridge/freezer

	Nominal volume (litre)			
	180 + 60		*260 + 70*	
Parameter	R12	R290/600a	R12	R290/600a
Charge (g)	110	50	—	—
Compressor type (cc)	5	5	8.5	8.5
Fridge temperature (°C)	5	5	5	5
Freezer temperature (°C)	−20.5	−19.5	−13	−16.4
Energy conservation (kWh/24 h)	1.65	1.52	2.47	2.32
Running %	66	58	69	63

  - The performance was measured on refrigerators taken directly from the production lines, particularly the R12 ones.
- The energy consumption results showed themselves to be very sensitive to the refrigerant charge. If R12 or R134a systems could tolerate variations in the gas quantity of some 10–20 g, the HC systems changed their behaviour in a perceptible way with ± 5 g only. The consequence of this is the choice of process-filling machinery, which must be more accurate than in the earlier ones.

Table 2c. Vertical freezer

	Nominal volume (litre)								
	120		*290*		*250*		*140*		
Parameter	R12	R290/600a	R600a	R290/600a	R12	R600a	R12	R134a	R600a
Charge (g)	95	55	54	50	160	65	110	100	37
Compressor type (cc)	5.5	—	13	8.5	7	11	4	5	8
Fridge temperature (°C)	—	—	—	—	—	—	—	—	—
Freezer temperature (°C)	−18	−18	−18	−18	−18	−18	−18	−18	−18
Energy conservation (kWh/24 h)	1.43	1.50	1.41	1.48	1.86	1.62	1.25	1.37	1.24
Running %	40	49	35	40	55	62	56	55	51

- The results have always been positive to the R600a use. The fact that the gas density positively affects the global efficiency of the compressor has supported the decision to provide compressors for R600a with run capacitor whose efficiency improvement is significant.
- The HC blend R290/600a (50:50) can be considered as a drop-in refrigerant for R12 as far as performance is concerned. Of course, the use of it as retrofit must be carefully analysed because of the flammability and safety issues. The refrigerators to be eventually retrofitted were not originally designed to work with flammable refrigerant.

Noise

Noise evaluations have been originally carried out based on the conviction that lower the discharge pressure, lower the noise radiation. This is partly true barring a few experiences.

In general, the application of R600a on refrigerators produced an average reduction of 2 dB(A) *vs.* the corresponding R12 and even 3–4 dB(A) *vs.* the R134a applications. But on some refrigerators, a slight increase in noise was noticed and the cause of this was not understood.

A further investigation was carried out while making some design improvements on a compressor family expressly designed to be suitable for R134a and R600a. It showed us that much care must be put on the gas pulsation of both the suction and the discharge side of the system.

As a matter of fact, if for some reasons the peak factor of gas pulsation is high, the noise reduction effect using R600a becomes zero and this can only be explained with the physical characteristics of R600a.

The acoustical impedance:

$$Z = \frac{p}{V}$$

$$= \frac{p}{\sqrt{\rho r T}}$$

where p = sound pressure, ρ = density of the gas, ρ is lower with R600a and in general with HC than with R12 and R134a.

These data (Table 3) are calculated with gas temperature of 90 °C and pressure corresponding to the evaporating temperature of –23 °C for each refrigerant (1.35 bar for air).

Table 3. Acoustical impedance of different refrigerants

Gas type	Sound speed Co (m/s)	Impedance Zo (Pa x s/m)
R12	165	913.5
R134a	180	700.2
R600a	238	279.6
Air	381	372.1

The big difference in the acoustical impedance and in the sound speed explains, for instance, that the first natural pulsation modes are located at higher frequency levels for R600a. They are more likely to be nearer the high ear sensitivity field. Furthermore, they are transporting the higher acoustical energy content. For this reason, much care is required in putting gas pulsation to get the best advantages by the lower working pressures.

Technological changes on the compressor side

All the changes in the compressor technology are concentrated in two main branches: displacement increase and lubricant.

Displacement increase

The ideal goal of a good compressor manufacturer would be to replace the (R134a or R12) compressor with R600a, with the same overall dimensions and cooling capacity. But this is not always possible as, for example, 160 kcal/h can be obtained with an 8 cc with R134a or with a 13 cc with R600a and not all the compressor designs allow such an increase. Therefore, in some cases, the step-up in the compressor family is required.

Necchi has met with success in its experiment with replacement, and its effort at designing might spring up some surprises.

Lubricant

With R134a, the use of polyol ester lubricant is necessary. As a consequence of this, the compressor and refrigerator manufacturers had to face some undesired 'side-effects' such as:

- hygroscopicity (higher with polyol ester oil than with mineral lubricant);
- thermal stability [critical point particularly with additives (antiwear, etc.)];
- solubility of refrigerant (not all polyol ester lubricants get it at all temperatures); and
- material compatibility (to be inspected with all the traditional materials used in refrigerating systems – chlorine is an example).

All these aspects are conducive to sludge formation inside the capillary tube of refrigerating systems and deterioration in the performance.

Reasons for sludge formation

- *Excessive moisture content.* Through hydrolysis of the oil, an acid appears, which, as final compound, generates carbossilates (metallic salts). To prevent this, a good compressor and system dehydration must take place; proper molecular sieve must be used; and use of any additives must be avoided to the extent possible, which could act as a catalyst for the chemical reaction.
- *Excessive oxidation of the oil.* The final compounds can also be metallic salts coming from the combination of ester decomposition and metallic ion. A high level of vacuum can avoid this.
- *Chlorine.* Chlorine, combined with heat, can decompose ester giving the same consequence as before. Chlorine coming from polluted systems or from chlorinated cleaning agents must be avoided.
- *Temperature.* Temperature can cause the deterioration of the ester oil eventually promoted by impurities coming from system pollution (process mineral lubricant, oligomers extracted by plastics inside the systems are examples of potential catalysers).

The cleanliness of the refrigerating system is vital for its good long-term behaviour. Instead, in the case of R600a and HC blends, the lubricant can also be of mineral origin. Nevertheless, the very good solubility of the HC refrigerant with mineral oil must be 'managed' to avoid other problems. Some of them are listed below.

- If the amount of refrigerant is high (but this is only in the case of big refrigerators or commercial applications), the lubricant viscosity can be heavily affected by the dilution.
- The traditional naphtenic lubricants have the tendency to generate foam in the transitory of initial extraction on the refrigerant in liquid solution. Therefore, much attention must be paid to the lubricant choice.
- If foaming takes place at microscopic level between the friction surface, the lubricant film can be broken with negative effects on the long-term wear.

Flammability

The flammability, as a matter of fact, becomes a weak point considering the very small amount of refrigerant present in any domestic system. Nevertheless, some simple features can prevent any risk. A flame-quenching overload protector with a PTC starting device eliminates any ignition point near the compressor. Similarly, other changes in the food storage compartments can eliminate any risk.

Costs

As a consequence of the above-said elements, the cost of R600a compressor is equal or lower than R134a. One of the main reasons of this is the much lower cost of the mineral oil as against the ester one. This is valid for compressor displacement ranges where it is not necessary to change too many things to obtain the displacement increase in the same overall dimensions. Any other consideration on the refrigerant and other system component costs must be done on the refrigerator manufacturer side.

Conclusions

R600a can be a good refrigerant for domestic application, especially from the ecological and efficiency points of view. The global cost of such a refrigerating system is not higher than R134a, considering the changes needed to prevent any risk coming from the flammability of the gas.

The paper outlines the specific performance of R290/600a (50:50 or 60:40), which is similar to R12, and identifies them as thermodynamically drop-in solution.

HFC134a and hydrocarbon appliances in domestic refrigeration: market trends, conversion

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Introduction

Thank you very much for giving us the opportunity to introduce Liebherr's contribution to environment protection with chlorofluorocarbon/hydrofluorocarbon (CFC/HFC) phase-out technology. Details about the development of alternative refrigerants and foam-blowing agents and the practical use of hydrocarbon (HC) in foaming and final assembly as well as after-sales service will be given by other experts of this workshop.

The deadlines set up for the phase-out of CFCs are, in general, according to the Montreal Protocol. For Europe, it has been set up for the year 1996 and for Germany, Austria, Switzerland, and Sweden in 1995 itself. The deadline for hydrochlorofluorocarbons (HCFCs) is set for the year 2030, whereas for Europe, it is 2015. Even Denmark committed to phase out in 2002.

I would like to share some more information about worldwide phase out of CFCs and specially the development of Liebherr in this specific sector, including our qualification to share our experience in HC technology with the cooperation of partners all over the world.

As a member of the strongly diversified Liebherr Group, acting worldwide with activities in the production of construction machinery (cranes, earth-moving equipment, machine tools, material flow technology, and aircraft technology), we have experience of more than 40 years in refrigerator and freezer production, which we have been sharing for more than 17 years with technical partners worldwide. In production facilities of more than 100 000 m², we manufacture 1.5 million refrigerators and freezers (household and commercial) per year in Germany and Austria.

Foam conversion

Being a market leader in Germany and a major producer in Europe requires innovations in new developments, especially in CFC- and HFC-free conversion and energy-saving as the main targets in our days. Like most manufacturers, Liebherr started years ago to study and check all possible alternatives to replace the 50% reduced CFC11 foam by a clean solution. This was also done in the framework of the German Electrical Industry Association (ZVEI), where all important European manufacturers participate. Programme for Alternative Fluorocarbon Toxicity testing programmes were also involved.

Liebherr was looking for a final solution, *in order to change production equipment only once*. The aims were to keep: (1) ozone depleting potential (ODP) at zero; (2) global warming potential (GWP) to approximately zero; and (3) a very short atmospheric life-span. (Hydrocarbons 2–3 days; HFC134a ~16 years; CFC11 ~100 years.)

Liebherr started to work on this project in 1992. It took more than a year to come to the production level. Within this time, patent rights had to be cleared, developments of new appropriate foam components had to be initiated and material specifications as well as recipe formulas to be worked out. This was rather new then, whereas nowadays you will get all these things ready-made from specialized manufacturers. For the processing of cyclopentane, no existing example for this particular production was existing.

Through critical risk diminution, new safety systems were laid out together with the German TÜV (German Technical Association for Inspection/Acceptance) and had to be tested and accepted. Even the discontinuous procedure (single short shots of foam injection) had to be solved.

Cyclopentane was chosen, as it has the best insulation coefficient of all different pentanes in the gas phase (alternatives: isopentane and n-pentane in continuous operations). The first cyclopentane-foamed refrigerator was exhibited by Liebherr at Düsseldorf's Plastic Fair in Autumn 1992.

In 1992, after various tests, it was decided to phase out CFC11 by cyclopentane and CFC12 by HFC134a, in both the factories. The procedure was finalized and 100% conversion was executed in April 1993 with a maximum standstill of one week in each factory. Being the first of its kind in the world, this project was a formidable task, combined with the short realization period of only five months. Unfortunately, at that time, the R600a refrigerant technology was not mature. That is why we had to change to R134a first.

Simultaneously, we concentrated on further improvements, and the first refrigerator with isobutane as refrigerant was launched in February 1993.

Because of the direct greenhouse potential occurring with R134a, this refrigerant has come under pressure in some countries even before its generalized usage. An alternative had to be found as quickly as possible, which would have (practically) no direct effect on the earth's atmosphere, and has thermodynamic properties at least equal to those of R134a, so that it does not adversely affect the indirect greenhouse potential [altogether known as total equivalent warming impact (TEWI)].

Refrigerant conversion

Hydrocarbon refrigerants, which produce the best conditions in this respect, have been known for decades, but have never been properly considered because of their flammability. Thanks to the consistent public relations efforts of an environmental organization, this flammability was suddenly accepted with the best result that nothing now withstands the use of an HC refrigerant. Liebherr, therefore, made an extensive evaluation to find the best HC refrigerant.

To determine the optimum HC refrigerant, trials were carried out in the context of the test series on the three relevant appliance groups: (1) single-temperature refrigerator; (2) refrigerator with freezing compartment; and (3) freezer (including no-frost).

Our conclusion from tests carried out is that isobutane is the optimum refrigerant for all domestic refrigerators and freezers. The results in energy consumption and performance are the same or better when compared to R12 and R134a.

Through appropriate measures, such as (1) optimizing the foam system with cyclopentane, (2) adding insulation thickness, (3) optimizing the cooling circuit components for R600a, and (4) using high efficiency compressors, we achieved with cyclopentane and isobutane refrigerators up to 10% lower energy consumption as compared with R11 and R12 CFCs. Basically, R600a is a better alternative in the medium term, as it has very good thermodynamic properties and there is practically no direct contribution to the greenhouse effect.

From the safety point, it is now clear that no-frost units can also be changed to R600a. Just in a short time after the introduction of the HFC refrigerant R134a, a complete change of refrigerant is now imminent in the German and in the European domestic refrigerator sector as well.

This last change is gladly accepted by our after-sales service people, as technical problems with HCs are much more inferior to the ones faced with R134a (roughly 50% less). Therefore, where there has not yet been a conversion to R134a (e.g. developing countries), a changeover from R12 directly to R600a should be considered, without going through the difficult and costly route of R134a. Till now, Liebherr has converted more than 70% of the production.

Liebherr was the first manufacturer in the world to have phased out CFCs and HFCs in its total production in two factories. This technical conversion had been approved and certified by German TÜV-Südwest (a neutral safety inspection agency). Since April 1993, Liebherr has worked without any incident and has produced nearly three million refrigerators/freezers with cyclopentane and up to one million with isobutane.

During this period, Liebherr acquired a unique experience in this technology. For Liebherr at this moment, with conversion of the entire production to cyclopentane/R600a, environment problems resulting from direct influence of the materials are solved. Furthermore, we are trying to reduce the indirect damages of the environment caused by energy production for the use of the refrigerators and freezers (GWP/TEWI).

Worldwide phase-out of CFCs

The deadlines fixed by the Montreal Protocol and its amendments are well known. Especially in Europe, much shorter deadlines have been set up by national rules and laws. These regulations enforced by national consumer organizations and Greenpeace has led the industry to accelerate new developments.

Initiated by Liebherr, the cyclopentane foam was introduced into refrigerator manufacturing, and by the end of 1993, all German manufacturers had followed or even committed themselves to this change. In the meantime, all major European manufacturers have changed to cyclopentane. After some hesitation, other countries like Japan, New Zealand, Australia, and Turkey followed. Only USA and Brazil have not yet accepted cyclopentane as a mature technology, mainly due to national constraints.

As to the use of R600a, initial acceptance started in Germany, initiated by Foron and Liebherr. Nowadays, all German manufacturers have committed themselves to R600a, even for no-frost models. In other European countries like Italy, Austria, UK, Sweden, and Switzerland, major manufacturers have introduced a series of R600a models.

Japan, in general, not so committed to the Montreal aims, is still hesitating to apply R600a to their no-frost system. On the other hand, compressor manufacturers like Americold (USA), Embraco-Siccom (Brazil), Matsushita (Japan), and Goldstar (Korea) have started to produce R600a compressors on a larger scale.

Situation in Article 5 countries

In the past few years, a number of alternatives for R11 and R12 had been checked and tested, not only in Europe, Japan, and USA, but also in China and India. These substances had been mainly HCFC141b for the foam and R134a as refrigerant and also R152a, R22/R152a blends, and HC blends.

HCFC141b will not be selected in many countries because it offers only a temporary solution and does not have a good compatibility with cabinet liner material. Cyclopentane, however, has zero ODP and low GWP and has been successfully implemented in Europe. It is compatible with materials currently used in refrigerators and is durable and suitable for use in domestic refrigerators. Cyclopentane is comparatively cheap and is available in most countries.

The manufacturing technology for cyclopentane use is mature. Control systems have been established so that this technology may be applied even in developing countries with strict processing regulations and training of production staff. In order to assure an adequate margin of safety, the safety standards for any project should be equivalent to those in Europe.

The performance of R134a, R152a, R22/152a blends, pure HCs, and HC blends was investigated as refrigerants. Isobutane (R600a) was selected as the best substitute refrigerant, because it has zero ODP and negligible GWP, and offers a final conversion, unlike R134a. Use of isobutane as a refrigerant has been successfully commercialized in Europe. Isobutane is compatible with materials currently used in refrigerators and compressors. Isobutane, like cyclopentane, can be made available at reasonable prices in most countries.

In consideration of this fact, some of the leading European manufacturers (Liebherr, Bosch-Siemens, and Electrolux) have announced to convert their entire production to isobutane by the end of 1996. Such a step seems to be more and more feasible now for other manufacturers and countries too.

The Montreal Multilateral Fund (MMF) is considering HC as a viable alternative. A high ranking MMF/EC (European Commission) delegation has visited the German Liebherr factory as the first HC manufacturer worldwide in January 1995. Since the end of 1994, cyclopentane conversion projects are constantly approved by the MMF, among others for Iran, Argentina, China, Cameroon, Bulgaria, and Egypt.

At the Executive Committee meeting in Montreal in March 1995, the first complete HC conversion project had been approved, including cyclopentane and isobutane equipment and conversion of some refrigerator models to R600a. This pilot project was jointly presented by Germany and USA in cooperation with China, and will be carried out by Liebherr – to make a switch over by a famous Chinese manufacturer with Liebherr technology. The cyclopentane conversion had already been commissioned in June 1995, while isobutane will follow in early 1996. In the meantime, other complete HC conversion projects (cyclopentane and isobutane) have been approved – two in Argentina and two more in China.

In China, the first full HC refrigerator/freezer combination was sold to the market in September 1995. The model had been converted with the assistance of Liebherr and 6000 appliances had been sold by the end of 1995.

These examples show the growing interest for the HC technology in Article 5 countries, provided they get appropriate assistance. The assistance that these countries will need are, in general, as follows:

- conversion and partial replacement of equipment that are used at present;
- delivery of new machinery and equipment;
- installation, commissioning, trial operation, and test run;
- training at the technology supplier's plant and on the job;
- safety precautions and systems according to the highest available standards.

Most Article 5 countries are now ready to convert to cyclopentane as a foam-blowing agent, but are still not sure, whether to change to R134a first or directly to R600a. As these countries are eligible for funding from MMF, they may ask through their concerned governmental agencies for financial support in carrying out feasibility studies to find out the best suitable solution.

The World Bank and the German Agency for Technical Cooperation are ready to finance such studies that may result in the formal request for MMF-funding to the Executive Committee of the MMF for the implementation of the Montreal Protocol.

For more than 17 years, Liebherr has successfully executed and operated various projects in countries all over the world implementing Liebherr technology for local production of refrigerators and freezers. Liebherr is also prepared to share its unique experience in HC technology with cooperating partners all over the world. Any project executed by Liebherr will be according to German safety standards.

Synthetic and natural fluids in commercial refrigeration applications

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Introduction

Chlorofluorocarbons (CFCs), particularly CFC12 and CFC502, which have been used in commercial refrigeration, have to be replaced in the near future. Some industrialized countries propagate the use of hydrofluorocarbons (HFCs), such as HFC134a, as substitutes for CFCs and hydrochlorofluorocarbons (HCFCs). Some of the advantages and disadvantages of these expensive fluids, manufactured mainly in industrialized countries, in comparison to natural fluids, have been discussed in this paper.

For phasing out CFC12, HFC134a, which has a similar vapour pressure curve, is proposed as an alternative by its producers. Using HFC134a, only a few adjustments have to be made at the refrigeration cycle and to the compressor design. Similar to HFC134a, several HFC mixtures have been developed to replace CFC502 and, later on, HCFC22. These fluorinated substances do not damage the ozone layer, yet have very significant greenhouse warming effects. Nevertheless, several disadvantages of these fluids in connection with their refrigeration oils and remaining substances from manufacturing are evident.

Natural fluid technology offers similar performance, often higher, using the same oils, components, elastomers, and production processes like CFCs. This technology is based on the safe use of hydrocarbons (HCs) for refrigerators, small commercial and air-conditioning equipment; while for larger air-conditioning systems and industrial uses, ammonia is proposed.

Today, HCs are being used in domestic refrigerators, and increasingly in the field of commercial refrigeration, air-conditioners, and heat pumps. It is expected to increase further in the near future, especially for small compact units. The flammability of HCs has to be considered for production and lifespan of the appliance. To ensure safe operation, changes have to be incorporated in the design.

In appliances with more than 50 kW cooling capacity, an alternative for the use of CFCs is ammonia. The general know-how concerning construction, servicing, and operation of ammonia equipment is available worldwide. New technologies allow to use ammonia with techniques similar to those used with CFCs. They improve the cost-effectiveness of small ammonia plants also to the level achieved with HFCs; in the case of larger equipment, it is even further. Manufacturers, who are converting to HCs or ammonia, choose long-lasting alternatives (to CFCs), which are free of patented substances such as HFCs and synthetic oils.

Hydrocarbons in commercial refrigeration appliances

The successful application of HCs in the field of domestic refrigeration induced an increased interest in natural fluids in appliances other than refrigerators. Presently, developments are focused to phase out CFC12 and CFC502, and now HCFC22 also.

CFC12 is used almost universally. The range of applications varies from large water chillers to refrigerators with small hermetic commercial equipment, automotive equipment, and especially in hot climates, all kinds of transport and storage equipment in between. CFC502 is mainly used by commercial units to freeze food. HCFC22, scheduled to be nearly phased out in industrialized countries by 2020, is mainly used in air-conditioning equipment.

Which hydrocarbon should be used?

Fluid properties

Small compressors, i.e. compressors with a low swept volume, are often cheaper, but they are less efficient than large compressors. With the increase in number of small compressors, cost advantage and efficiency decrease disproportionately. Very small compressors are not significantly cheaper than those having twice the size, but significantly more inefficient. HC600a (isobutane) is a refrigerant widely used in small appliances up to 500 W capacity (such as refrigerators). Nevertheless, if the desired capacity is higher than 500 W, the use of HC290 (propane) is more economical.

Based on the positive experiences with isobutane as a refrigerant in domestic refrigeration, other small compact units have also been developed. At present, units with isobutane as refrigerant with approximately 300 W cooling capacity are available. These are plug-in units, which are hermetically sealed and thoroughly checked for leakage by the manufacturer.

Not only for larger capacities but also for low-temperature appliances and heat pumps, propane shows excellent thermodynamic and thermophysical properties. Like isobutane, propane is flammable. Propane is an advantageous substitute for HCFC22 due to its similar temperature–pressure behaviour. It is also a good substitute for CFC502 due to the low compressor discharge temperature. The advantages concerning the use of standard refrigeration oils and the absence of problems related to a high humidity content of ester oils are similar to those of isobutane. The work quality achieved with CFCs is sufficient for the use of propane.

For the widely used, cost-effective single-stage refrigeration system, propane allows higher temperature differences between evaporation and condensation than is possible with ammonia or HCFC22 because of its low compressor discharge temperature. For this same reason, propane can also be used as a substitute for CFC502 in a single-stage system; while a replacement with HCFC22 or ammonia would require an expensive two-stage compression system.

The refrigeration oil is an important aspect for refrigerant selection. The new HFC substances require a totally new, synthetic refrigeration oil for compressor lubrication. Such a refrigeration oil, partly circulating with the refrigerant in the refrigeration cycle, is extremely important for the lifespan of the system. Oils that have been developed for HFCs are expensive and highly hygroscopic. The presence of water in the oil causes chemical breakdowns and formation of new substances in the cycle, and reduces the lifespan of the compressor. Thus, the presence of liquid or vapour has to be avoided in the cycle.

This problem requires a reorganization of the production to ensure that the compressors and all other parts are highly dried after manufacturing and sealed airtight, to be opened only directly before assembly. In addition, exceptional attention must be paid to the cleanliness of parts in case of utilization of capillary tubes as expansion devices or at low temperature applications. In these cases, severe difficulties like capillary tube blocking have been reported because HFCs are very sensitive to contamination by chemicals from production or service. The fulfilment of most of these requirements cannot be monitored by some kind of test equipment, but depends highly on the responsible action of each person involved in the production of components and the product. If a minor mistake has been made, it may not be noticed before the customers lay claim to the warranty a few month later. These difficulties increase further while servicing. If the refrigeration cycle is opened for service purposes, the oil has to be removed completely, which is virtually not possible without removing the compressor from the cycle and opening it, and it is a time-consuming operation.

In addition, the service has to use a high-quality low vacuum pump with a special vacuum pump oil, and the new oil has to be taken from containers sealed by the oil manufacturer until service. Oil containers opened hours before use, e.g. at the earlier service location, cannot be used because of the rise in humidity content.

Considering the fact that this will require significant investments into a new vacuum pump, longer working time for the service, higher costs and different handling of the refrigeration oil, as well as the fact that the customer has no means to control the quality of work, it has to be expected that the service will often not be carried out in the quality required. This may very well lead to compressor replacements as often as every year to keep the refrigerator running. The costs for each household and for the economy are very significant, at the same time decreasing the trust of the consumer into the manufacturer whose product he originally purchased.

A second alternative for the replacement of CFCs such as CFC12 or CFC502 is the use of HCs. Isobutane, propane, and their mixtures are HC derivatives produced in petrochemical plants. The technology with HCs as refrigerants is compatible to CFC technology. This means that HCs are miscible with the same oils and can be sealed with the same elastomers. HCs and their oils are not hygroscopic and not sensitive to contamination by chemicals from production or service.

Other aspects

Propane is fully compatible with most materials used with CFC12 or HCFC22. As stated above, the same type of refrigeration oil can be used as with CFCs. However, due to the high solubility of HCs, in some cases, it might be necessary to choose a refrigeration oil with the next higher viscosity class.

Especially when changing from CFC502 or HCFC22 to HCs, no specific adjustments are necessary to most of the components. Usually, the same heat exchangers can be used without a recalculation. If converted from HCFC22 to propane, a change of the filling of thermostatic expansion valve can be avoided, but an optimized filling is recommended. Using capillary tubes, length and diameter have to be optimized.

To ensure product safety, leakage and ignition sources have to be minimized. To reduce the hazards, potential leak sources, such as joints, should not be placed in the space to be cooled. To avoid the presence of a flammable mixture next to an ignition source, electrical switches with IP54 protection should be used. This will minimize gas exchange between switch housing or cabinet and its environment. Additionally, the refrigerant charge of the appliances should be minimized. This can be realized by compact design. Referring to component changes, the compressor displacement has to be adjusted to the refrigerant to achieve similar capacity. Furthermore, the use of piston rings is recommended to increase the efficiency.

Presently, all manufacturers producing HC systems other than refrigerators use standard compressors, e.g. HCFC22 compressors for HC290. Examples for systems existing on the market are given below.

Systems on the market

Heat pumps. All German heat pump manufacturers are in the process of a complete switchover to HC290 as a working fluid. In general, the producers achieved higher efficiencies with HC290 than with HCFC22 or other halogenated substances. At the same time, the condensing temperature could be increased because of the low discharge temperature of propane. The various types of production consist of hot tap water heat pumps with 1.5 to 2 kW capacity and heating systems with 5 to 35 kW capacity. Also, heat pumps for dehumidification of indoor swimming pools are equipped with propane.

Room air-conditioners. An Italian and a German manufacturer produce air-conditioners with propane as a working fluid, with capacity between 1.9 and 2.4 kW. The Italian producer, DeLonghi, is the European market leader for small air-conditioning systems. While only compact units are available at present, DeLonghi announced split systems using HCs for 1996. These units are stored and sold in warehouses, to be self transported and installed by the consumer.

Commercial systems. For commercial refrigeration purposes, only a few systems have been developed so far. This is, on the one hand, due to the delayed availability of information regarding safety technologies; on the other hand, numerous small enterprises do not announce the use of HCs on a large scale, thus never coming to the attention of the author.

Nevertheless, some examples are known, e.g. a shop in the inner city of Frankfurt where the freezing room is cooled by propane in a split application. In this refrigeration plant, with a charge of 2.5 kg propane, a standard HCFC22 compressor and a standard HCFC22 thermostatic expansion valve are used. The safety equipment consists mainly of a gas detector while all the electrical equipment is IP54 sealed.

Handling of equipment in the field

General. The lifespan of equipment in the field is often significantly higher than 20 years. A huge amount of equipment is already in the field, using CFCs as working fluid. Also, the continuing use of HCFC22 will cause significant amounts of installations with CFC technology. After the transition to CFCs, the CFC technology and its replacement will be present in the field. Such compatibility is highly desirable.

During the system lifespan, usually several repairs of the equipment take place. The filling of the refrigeration system has to be topped or replaced often, in case of major accidents. Using two different refrigerants in basically similar equipment, the risk of mistakes like filling of the wrong refrigerant is possible. The decision for a new refrigerant should reflect these difficulties sufficiently.

Service. Repairs are carried out mainly by small enterprises who form the unorganized or informal sector. They have to work very cost-effectively, while the customer has no real means of insuring quality.

It is virtually impossible to train the entire unorganized sector in the handling of sensitive refrigerants, lubricants, and equipment with respect to cleanliness, humidity, etc. and convince them to purchase new vacuum pumps, handle the oil properly (e.g. never use an oil can with an open lid, no matter what the content is), and so on. These things have to be taken care of while using HFC technology, otherwise the negative effects arising out of improper handling will start surfacing after a few months.

On the other hand, the service technicians, who are already trained in the use of flammable gases, can handle HC refrigerants appropriately with the help of soldering torches. Since HFCs are much more sensitive to improper handling than the HCs, and as compared with the hazard that moisture constitutes for the lubricants required for HFCs, HCs are considered to be better choice for commercial refrigeration equipment in developing countries.

Drop-in and retrofitting. The availability of CFC12 and CFC502 for repairs of appliances using these refrigerants will decrease in the near future, causing the need for other refrigerants to be charged.

In general, a refrigeration system is designed for a specific refrigerant. This relates to the dimensions of compressor and heat exchangers as well as the material used. If the original refrigerant is exchanged and replaced by another one, it can be distinguished between drop-in and retrofit. Drop-in means the exchange of refrigerant without any modifications and retrofitting with some changes.

HFCs cannot be used for drop-in of CFC applications because of the immiscibility with the lubricant, insensibility to contaminants, missing material compatibility, etc. Charging with HFCs will result in severe damage of the application, unless an extensive flushing procedure has been carried out. In the case of small- and medium-sized hermetic compressors, which usually do not have an oil drain plug, the compressor often has to be removed from the cycle and opened.

In contrast, HCs can be used with relative ease as a replacement for CFCs. For CFC12, a mixture of isobutane and propane [approximately 50% (mass) propane] has nearly the same refrigerating capacity as CFC12. For the replacement of CFC502, HC290 can be used if (approximately) 5% to 10% decrease of capacity can be accepted. The discharge temperature of HC290 is even lower than that of CFC502. If the same capacity is necessary, a mixture of propane and ethane is possible and is commercially available. With those mixtures, a similar refrigerating capacity with a slightly lower efficiency due to less favourable heat transfer values can be achieved.

If HCs are used as a drop-in refrigerant for CFCs, the safety requirements of the application have to be considered. Most likely, some components have to be replaced to ensure that no ignition sources are present at exposed spaces, e.g. in a limited space to be cooled. The switch box or fuse box has to be replaced by a box with IP54 protection, where all switching elements are located. Klixxon devices mounted outside the compressor have to be sealed, e.g. using silicon. However, in some cases, the use of HCs as replacements in old equipment will not be appropriate due to safety considerations.

Safety

Hydrocarbons like propane and isobutane are flammable. Therefore, the safety aspects of applications with HCs have to be considered carefully. The main objection to the use of HCs as refrigerants is the flammability of these fluids, whereas alternative HFCs are either not flammable or mixed in a way that their flammability is suppressed. However, demixing might still cause formation of an explosive mixture in very rare cases. In addition, if the pressure is higher than ambient pressure, HFCs can also form explosive mixtures with air, e.g. HFC134a at approximately 1 bar above atmospheric pressure.

Safety concerning flammability aspects must be considered for HCs and their mixtures during production, distribution, use, recovering, and recycling. The safety principle for the use of HCs is very simple if one reflects the basic idea: the coincidence of the necessary conditions for an accident, i.e. a flammable mixture of air and working fluid and an ignition source has to be avoided.

To generate a flammable mixture in a room with around 16 cubic meters (2.5 × 2.5 × 2.5 m), 670 g isobutane or propane is necessary assuming even dispersion. Typically a 165-litre domestic refrigerator would contain about 30 g, with some 10 g remaining in the oil in case of a major rupture. Room air-conditioners discussed above contain approximately 300–500 g of HCs. Typical leak rates vary between 0.5 g/year and 3 g/year for products manufactured in a highly sophisticated way in large factories (refrigerators, air-conditioners) and around 100 g for very poorly manufactured applications.

Additionally, it must be taken into account that refrigerators are often repaired in developing countries, either in contract workshops or in free workshops. To avoid the risk of explosions during repair or resulting from faulty repair, the following measures are proposed:

- reducing the possibilities for faults;
- leak testing as part of routine maintenance; and
- training programmes for technicians of factory workshops and those of the unorganized sector during transition period.

At the moment, there are only few commonly agreed guidelines for the design of applications. Presently, Germany is the only country in the world possessing approved safety standards for HCs in appliances other than domestic refrigerators

(DIN 7003). European standards are presently under preparation [EN 378 (available as preliminary print), EN 60335, part 40 (yet not available)]. Also several national standards are under preparation, which often use the DIN 7003 as example. Once the safety standards are defined, it is expected that the market share of HC refrigeration systems will increase significantly.

Ammonia in commercial refrigeration applications

Ammonia is a well-known refrigerant used in large-scale industrial applications for more than 120 years. The know-how concerning the technology is widely dispersed in developed and developing countries. Nevertheless, it has not been used in air-conditioning appliances or small refrigeration plants, despite the fact that ammonia has excellent thermodynamic and thermophysical properties, high efficiency in most temperature ranges, no ozone depleting potential, no global warming potential, low refrigerant cost, great tolerance to water contamination. Due to its strong smell, it is easily detectable even at very low concentrations [five parts per million (ppm)].

The reasons for not considering ammonia for the systems mentioned above are given below.

- Toxicity at low concentration in air
- Flammability at high concentration in air
- No compatibility with zinc or copper or copper containing alloys' high discharge temperatures

For large systems, the disadvantages of ammonia mainly concern safety; for small systems, there are presently additional cost disadvantages.

The toxicity of ammonia is usually not a major concern; the smell is noticed by man at concentrations as small as 5 ppm. At the same time, the threshold limit value, which should not be exceeded for everyday exposure, is 50 ppm. Ammonia is unbearable for human beings at 500 ppm, while its acute toxicity starts at 2500 ppm and the flammability at 15 vol. %. Obviously, any hazard announces itself far in advance, making ammonia actually a very safe refrigerant concerning direct hazards.

Unfortunately, there is an indirect hazard caused by ammonia in public areas. Heavy ammonia concentrations might cause (unnecessary) panic among those who are not familiar with the smell. The main focus of safety measures is, therefore, to avoid a fast increase in ammonia concentration in public areas up to or above the panic level.

The safety rules for ammonia plants are very simple. No parts of a plant should be in direct contact with the public, and systems should be installed to hold back significant ammonia in case of a major rupture. While the former causes the need for indirect systems, which are always present in the case of water chillers; the latter leads to housings around the systems, often combined with a water tank. The water in such a tank allows to dissolve a significant amount of ammonia completely. Fifty litres of water can dissolve up to 50 kg of ammonia. With such an amount of ammonia, systems up to 1.4 MW can be built.

Applications

Air-conditioning

Air-conditioning of large buildings is often performed by centralized air-conditioning systems with capacities above 700 kW, which use cool water circulating through the building to distribute the cooling capacity. In the past, centrifugal chillers were used, utilizing mainly CFC11 as refrigerant. Because of the toxicity concerns with HCFC123, the existing old CFC11 equipment is often not converted to HCFC123 but replaced by new equipment using HFC134a. If this is the case, ammonia is a very attractive alternative because, instead of replacing the old CFC11 by a new centrifugal chiller, an ammonia plant can be installed. These ammonia plants can be placed as rooftop units, as stand-alone units next to the building or in the basement. In this case, a duct for forced ventilation, in case of major ammonia emissions, should be installed.

Supermarkets

Presently, the use of ammonia plants for cooling of medium and large supermarkets is increasing. This is due to the introduction of secondary refrigerant (brine) systems into the market, which have several advantages. These brine systems distribute a cold secondary fluid, e.g. a water–glycol mixture to the different cooling or freezing cabinets. While the brine is increasing its temperature when running through the heat exchanger in the cabinet, it is cooled down in the evaporator of a centralized, pre-fabricated refrigeration plant which can be located in a machine room inside or outside the market.

The advantages of those systems are, on the one hand, low refrigerant emissions of the refrigeration plant because of compact design and quality control during the manufacturing process. On the other hand, the control of secondary fluid systems is much easier than the control of direct expansion systems when numerous cabinets have to be cooled. Third, the brine system can often be constructed by personnel with a low level of training, making the construction cheaper and easier to organize. Using a secondary system in supermarkets, ammonia systems can be easily applied to generate the necessary cooling capacity, because all ammonia containing parts can be placed outside the public shop area.

Recent technical developments

Recent developments introduced copper-free aluminium alloys as construction material for tubing and fluxing material for these aluminium alloys. This allows, with soldering of parts and bending of the pipework, a manufacturing process similar to those of CFC plants instead of the ammonia technology of welding steel pipes, thus reducing the costs of installation.

Ammonia systems could not be operated in a self-controlled manner due to the immiscibility of the refrigeration oil with ammonia. In 1992, a soluble oil based on polyalkylene glycols (PAG) was introduced into the market which enables oil to return to the compressor in the same way as CFCs do. In the meantime, different soluble oils for ammonia from several manufacturers are on the market.

The acceptance of ammonia in the public can be increased and the demand for safety equipment can be reduced by a minimized refrigerant charge and hermetically sealed system. A significant reduction of charge is enabled by dry expansion evaporation. A basic requirement for this is the application of a soluble oil. At the same time, the new technology of soluble oils allows the use of newly developed ammonia-resistant plate heat exchangers as evaporators and condensers, which again reduces system refrigerant charge. Motivated by the increasing interest in ammonia, several compressor manufacturers developed new ammonia compressors. In the recent years, semihermetic and hermetic compressors have been developed.

Market share

Refrigerant manufacturers, who could produce HFCs, promoted all kinds of CFC control, and using their immense public relation possibilities advertised HFC as the only alternative to CFC and HCFC. At the same time, the process of tightening up regulations constantly led to concerns among original equipment manufacturers (OEMs) and customers: What would happen if they choose an alternative to CFCs which might be obsolete in the near future? Who would repay their investments into new refrigeration and production equipment?

Naturally, these questions were first asked in the case of major investments. Thus, the water chillers with large refrigeration capacities, using HCFC123 and HFC134a as alternative refrigerants, came under market pressure. An alternative for HCFC and HFC technology was already present. The ammonia technology, for 120 years, established for large refrigeration capacities in industrial and food processing applications, had only to be supplemented by safety features, such as a minimization of filling mass, gas-tight housings, and water tanks to solve escaping ammonia in.

Hydrocarbons

For the same reasons, first researchers and then industrial manufacturers of refrigeration equipment started to look into the so-called natural refrigerants as alternatives for CFCs. Due to state-of-the-art present in the small refrigeration systems, a non flammable working fluid – HC – was not considered first. But other natural alternatives failed as short-term solutions because of necessary investment costs for conversion of production and other equipment shortcomings. Thus, HCs, requiring only well-known technology inside the refrigeration cycle, were reconsidered.

The announcement of the use of HC technology by the German refrigerator manufacturer Foron, heavily supported by Greenpeace, forced other larger refrigerator companies to prove their ability to develop similar models; the sale success of the Foron refrigerator enhanced the marketing of those models. Surprisingly enough, marketing was a major success for those refrigerator companies which were ahead of the competition. In 1993, all Western European refrigerator companies, selling to the German market, started to convert their production step-by-step from HFCs to HCs.

This movement to HCs caused OEMs in other fields to reconsider their attitude towards HFCs. The first were some specialized OEMs for certain types of commercial refrigeration like beer coolers which advertised equipment charged with HCs already in 1993. In early 1994, the German manufacturers of heat pumps announced that they would start with the production of equipment charged with HC290 soon, which they did in spring. The latest product group are air-conditioners which use HC290 as working fluid; they are available in the market since spring 1995.

The development for refrigeration applications other than household refrigeration is divided into two directions. First, the development of HC applications to larger refrigeration capacities can be noted; and second, the ammonia applications tending to large air-conditioning systems, and also to medium capacity systems for commercial use with secondary systems.

The use of HCs in household refrigeration also caused manufacturers of other refrigeration applications to consider those refrigerants. While several small enterprises started, soon after the refrigerator industry, to promote HC systems, e.g. for beer cooling, the first major use of HCs in refrigeration applications was the use of heat pumps, produced on an industrial scale. Since mid-1994, heat pumps with HCs are available in the market on a large scale. The main technical difference from household refrigerators is in the amount of filling, which is up to 2 kg of HC290. In this year (1996), the market share of the HC heat pumps for space heating is close to 100% in Germany, a market with approximately 1500 space heating heat pumps per year.

Other refrigeration industries also work on HC technology. In the meantime, systems for cooling of switch cabinets and for drying of pressurized air have been developed; while at the same time, the number of producers of small, customized refrigeration systems for the commercial market with HCs as working fluids is increasing.

Ammonia

New applications of ammonia as working fluid are supermarket applications and centralized air-conditioning systems. In the case of supermarket systems, the necessary development of suitable brine systems to distribute secondary refrigerants slowed down the development. Presently, there are seven supermarkets in Luxembourg, four in Switzerland, two in Italy, and two in Germany, whose medium and low temperature display cabinets are cooled by ammonia plants.

The use of ammonia in air-conditioning systems is now a widely accepted technology. Presently, the market share of large air-conditioning systems with ammonia is reported to be close to 100% in Sweden and Luxembourg and around 30% in Germany and Switzerland. In general, the ammonia market for air-conditioning is well developed in the Middle and North Europe. In the southern countries of Western Europe as well as in Great Britain and France, only small market shares of ammonia plants in large air-conditioning systems have been achieved so far.

Conclusions

Natural refrigerants in general, and HCs in particular, are suitable for refrigeration purposes in industrialized and developing countries. The safety issues, which have to be considered, can be solved with technology and know-how available for decades.

The refrigerants are cheap and accessible; the know-how for their handling is available. Natural fluids have proven to perform similar or better than any alternatives in a refrigeration cycle.

The technology to be used is proven. Several manufacturers selected this technology for their large-scale production. Among those are subsidiaries of the world's leading refrigeration companies. For the use of CFC502 and HCFC22, there is no really convincing long-term HFC solution available yet. This technology requires a high level of organization in production and service.

Even if the required quality in production processes can be achieved in factories in developing countries, a sufficient level of quality in the manufacturing of the various component suppliers is doubtful. It is also certain that the unorganized service sector will not be able to fulfil all the requirements of proper operation.

Thus, it seems to be worthwhile to consider natural fluids in general, and HCs for refrigerators and small hermetic applications in particular, as an alternative option to the HFC technology. *Cui bono?* (Who benefits?)

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Hydrocarbon refrigerants: properties, purity, and safe handling

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Introduction

Considerable experience has been gained in the UK in the training of refrigeration technicians and in the safe application of hydrocarbon (HC) refrigerants in different domestic and commercial refrigeration and air-conditioning appliances. This paper is based on the training manual produced for the UK and Australian markets. It covers the aspects listed below.

- Introduction to HC refrigerant range from Calor Gas
  - Physical properties
  - Environmental effects
- Performance of HC refrigerants
  - Operating conditions
  - Capacity and efficiency
  - Charge quantity
  - Use in new and existing systems
- Handling of HC refrigerants
  - General safety issues
  - Charging
  - Leak detection

Introduction to hydrocarbon refrigerant range

Hydrocarbons are very good refrigerants and widely used in many appliances. The advantages of HCs over halocarbon refrigerants are:

- zero ozone depletion potential (ODP);
- very low global warming potential (GWP); and
- good performance characteristics.

Table 1 summarizes the Calor Gas HC refrigerant range.

Table 1. Calor Gas HC refrigerant range

Refrigerant	Boiling point (°C) at atmospheric pressure	Composition	Application
R600a (Care 10)	−12.0	Isobutane	New domestic equipment
Care 30	−31.5	Zeotropic HC binary blend	Drop-in replacement for R12 (and R134a)
R290 (Care 40)	−42.0	Propane	New high, medium, and low temperature equipment
Care 50	−49.0	Zeotropic HC binary blend	Drop-in replacement for R22 and R502

R600a

R600a is pure isobutane (also known by the trade name Care 10), and is primarily used in new domestic type equipment. It operates at significantly lower pressures than R12 or R134a, and hence its use requires modifications to components. It is not designed for existing R12 or R134a systems.

Care 30

Care 30 is a purified blend of propane (R290) and isobutane (R600a), with a boiling point of −31.5 °C at atmospheric pressure. The blend has been developed to produce a refrigerant with a capacity similar to R12. Its major use will be in domestic refrigerators, small commercial systems and transport refrigeration, and air-conditioning appliances. Though Care 30 has been formulated as a replacement for R12, it can also be used in R134a systems.

The advantages of Care 30 are: (1) it has superior energy efficiency; (2) it has capacity similar to R12; (3) it is compatible with R12 system components, including oil; and (4) no system modifications are necessary, i.e. no change of compressor, evaporator, condenser, Thermostatic Expansion Value (TEV), etc.

R290

R290 is pure propane (also known as Care 40), and is primarily used in new equipment, which would traditionally have used R22 or R502 (or ammonia). If used in existing R22 and R502 systems, it may not give the same performance as R22 or R502, and modifications may be required.

Care 50

Care 50 is an HC blend, developed to replace R22 and R502 in existing installations with minimum modifications to the system. It can also be used in new systems. It has a boiling point of −49 °C at atmospheric pressure. The most important properties of Care 50 as a refrigerant are listed in Table 2, along with data for R22 and R502.

The importance of the correct blend and purity

The HC refrigerant range has been developed to give specific operating conditions and performance. Commercial propane and butane must not be used. These fuel grade products are of variable composition and contain impurities, including moisture, which would significantly reduce the reliability and performance of the system, and would lead to premature failure.

Refrigerants should be produced to the ARI 700 standard for new refrigerants (Air Conditioning and Refrigeration Institute - USA). This specifies very low levels of impurities (e.g. moisture, solids, and acids) allowed in virgin refrigerant.

In Care 30 and Care 50, the blend composition is important. Using a blend with a different composition may result in:

- operation at different pressures and temperatures, which may be detrimental to system component performance and reliability; and
- significantly lower capacities and/or efficiencies.

Effect of hydrocarbon refrigerants on the environment

Hydrocarbon refrigerants are natural substances with very short atmospheric lifetimes – weeks and months rather than 100+ years for chlorofluorocarbons (CFCs).

Table 2. Table of physical properties

Property, metric unit, weight basis	R600a	R12	R134a	Care 30	R22	R290	R502	Care 50
Boiling point at 1 atmosphere (°C)	−11.80	−29.80	−26.10	−31.50	−40.80	−42.10	−45.40	−49.00
Specific heat of liquid at 30 °C (kJ/kg K)	2.49	0.99	1.45	2.54	1.27	2.80	1.26	3.01
Specific heat of vapour at constant pressure at 30 °C (kJ/kg K)	1.86	0.62	0.86	1.70	0.91	2.12	0.69	1.71
Ratio of specific heats (C_v/C_p) at 1 atmosphere (30 °C)	1.10	1.14	1.12	1.15	1.18	1.10	1.13	1.10
Density of liquid at 30 °C (mg/m^3)	0.55	1.29	1.19	0.52	1.17	0.48	1.19	0.48
Density of saturated vapour at boiling point (kg/m^3)	2.81	6.3	5.3	2.6	4.7	2.40	6.2	2.22
Latent heat of vaporization at boiling point (kJ/kg)	362.00	165.00	217.00	405.00	233.00	426.00	172.00	444.00
Thermal conductivity of liquid at 20 °C (W/m°C)	0.10	0.07	0.08	0.10	0.09	0.09	0.07	0.10
Thermal conductivity of vapour at 30 °C, 1 atmosphere (W/m°C)	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.02
Surface tension at 25 °C (mN/m)	9.55	8.50	8.40	8.60	8.10	7.03	5.44	7.92
Viscosity of liquid at 30 °C (centipoise)	0.14	0.19	0.20	0.11	0.15	0.09	0.17	0.08

Once in the atmosphere, they break down to carbon dioxide and water. Although carbon dioxide is a greenhouse gas (GHG), it is a very weak one. The significant effect of carbon dioxide on global warming is due to the very large quantities released through burning fossil fuels for power generation. The amount released by the use of HCs as refrigerants would be an extremely low proportion of the total.

HC refrigerants contain no chlorine or bromine and, therefore, have no ODP. Their GWPs are related to the carbon dioxide produced when they break down in the atmosphere and are compared to other refrigerants (Table 3).

Other replacements for R12, R22, and R502 based on hydrochlorofluorocarbons (HCFCs) and/or hydroflourocarbons (HFCs) have GWPs of the same order as those for R134a and R404a.

Total equivalent warming impact

The total equivalent warming impact (TEWI) is a measure of the total impact of a refrigerant in a system on global warming. Refrigeration systems can contribute twice to global warming:

- directly through emissions of those refrigerants which are GHGs; and
- indirectly through the use of energy generated by burning fossil fuels (which cause carbon dioxide emissions).

TEWI = direct effect + indirect effect

Table 3. Comparison of refrigerants based on GWP and ODP

Refrigerant	GWP (500 year basis)[1]	ODP[2]
R600a (Care 10)	<4	0.00
Care 30	<4	0.00
R12	4500	1.00
R134a	420	0.00
R290 (Care 40)	<3	0.00
Care 50	<3	0.00
R22	510	0.05
R502	4000	0.31
R404A	1400	0.00

[1] GWP relative to carbon dioxide = 1; [2] ODP relative to R12 = 1

The TEWI can be reduced by:

- using a refrigerant which has a GWP as low as possible;
- reducing emissions of that refrigerant;
- improving the energy efficiency of a system by using an efficient refrigerant and by implementing generic energy efficiency techniques and technologies.

HC refrigerants virtually eliminate the direct effect because of their very low GWPs. Improved energy efficiency also reduces the indirect effect.

Performance of hydrocarbon refrigerants

The major points to be considered while applying HC refrigerants are given below.

- Operating pressures and temperatures
- Temperature glide (where applicable)
- Capacity and efficiency
- Charge quantity
- Compatibility with system materials
- Application in new and existing systems

Like many of the new alternative refrigerants, Care 30 and Care 50 are zeotropic blends, i.e. they do not behave like a single substance. This introduces some differences in application and use. In application terms, this mainly concerns temperature glide in evaporators and condensers. Flammability also affects the handling of the refrigerant and, to a certain extent, the system design.

Operating conditions

Figures 1 and 2 compare the pressure–temperature relationship of the HC refrigerant range with traditional refrigerants. R600a (Care 10) operates with much lower pressure than other refrigerants shown, and is designed for use in new systems.

Care 30 is formulated to operate with pressures similar to R12. It can be seen that at evaporating conditions, the pressure of Care 30 will be slightly higher than either R12 or R134a, and at condensing conditions, the pressure of Care 30 will be lower. Care 30 will, therefore, operate with a lower compression ratio, thus improving the operation of the compressor. The discharge temperature of Care 30 is similar to R12 and R134a at the same evaporating and condensing temperatures.

R290 (Care 40) operates with pressures similar to R22 at evaporating conditions and slightly lower pressures than R22 at condensing conditions. The compression ratio is, therefore, slightly less than that for R22; the discharge temperature of R290 is less than that for R22.

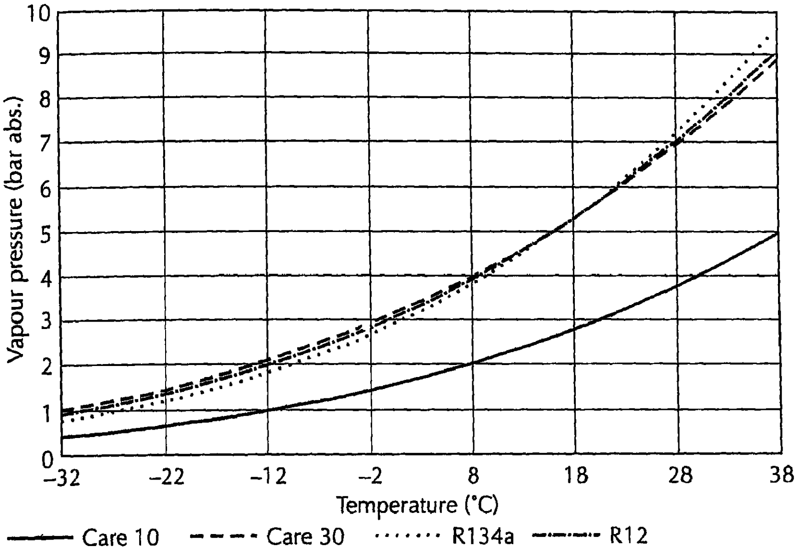


Figure 1. Pressure–temperature relationship for Care 10 and Care 30 against R12 and R134a [Vapour pressure versus temperature profile for R12, R134a, Care 10, and Care 30]

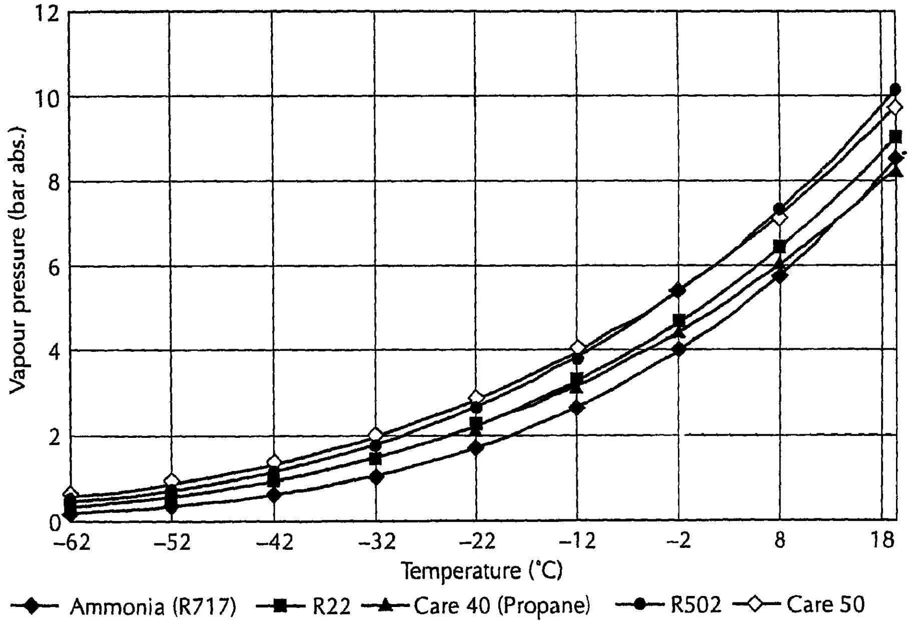


Figure 2. Pressure–temperature relationship for Care 40 and Care 50 against R22, R502, and ammonia [Comparison among Care 40, Care 50, R22, R502, and ammonia]

Care 50 operates with pressures similar to R22 and R502, although it is closer to R502. The compression ratio of a system operating with Care 50 will be less than those for systems using R22 or R502. The discharge temperature of Care 50 is less than that for R22 or R502 at the same operating conditions. The pressure–temperature relationships for the range is given in Table 4.

Temperature glide

As with all zeotropic blends, Care 30 and Care 50 have temperature glide. Data in Table 4 show the two temperatures (the bubble temperature and the dew temperature) corresponding to pressure for these two refrigerants.

The bubble temperature is the saturated liquid temperature (the temperature of the refrigerant when it is just pure liquid, but not sub-cooled). The dew temperature is the saturated vapour temperature (the temperature of the refrigerant when it is just pure vapour, but not superheated).

When a zeotrope boils, the composition of the vapour may not be the same as the liquid. The vapour could be richer in the component with lower boiling temperature. At the start of the evaporator, the temperature of the refrigerant will be higher than the bubble point because some of the refrigerant will have flashed off already during expansion. As the blend flows through the evaporator, its boiling point rises as the composition of the liquid phase changes. The evaporating temperature will therefore increase as the refrigerant flows through the evaporator and more of the blend evaporates. This is the temperature glide. In practice, it will not be as much as is indicated by the difference in the bubble and dew temperatures in the tabulated data and is in line with many of the other refrigerant blends now available.

The same effect occurs in the condenser. In this case, the condensing temperature will decrease through the condenser. Other effects of glide that apply to all zeotropic blends are given below.

- Ice build-up on an evaporator may be uneven due to the change in evaporating temperature through the evaporator.
- When checking superheat, the temperature of the refrigerant at the exit of the evaporator should be compared to dew temperature corresponding to pressure.
- The composition of the blend may be different in the vapour state. The refrigerant should, therefore, always be charged as a liquid.
- In non-hermetically-sealed systems, differential leakage may occur, depending on the location of the leak in the system.

Refrigerants with temperature glide are not best suited for use in systems with flooded evaporators.

Table 4. Pressure–temperature relationship for HC refrigerants

		Care 30			Care 50	
Pressure, bar gauge	R600a (°C)	*Bubble temperature* (°C)	*Dew temperature* (°C)	*R290* (°C)	*Bubble temperature* (°C)	*Dew temperature* (°C)
−0.7	−39.4	—	—	—	—	—
−0.6	−33.4	—	—	—	—	—
−0.5	−28.6	—	—	—	—	—
−0.4	−24.5	—	—	—	—	—
−0.3	−20.9	−40.2	−31.4	−50.1	−57.3	−51.1
−0.2	−17.7	−37.2	−28.4	−47.3	−54.4	−48.3
−0.1	−14.8	−34.4	−25.6	−44.7	−51.7	−45.8
0.0	−12.1	−31.9	−23.2	−42.4	−49.3	−46.5
0.5	−1.2	−21.6	−13.0	−32.8	−39.6	−34.0
1.0	7.1	−13.7	−5.2	−25.4	−32.1	−26.7
1.5	14.0	−7.1	1.2	−19.4	−25.9	−20.7
2.0	19.9	−1.5	6.7	−14.2	−20.6	−15.6
2.5	25.0	3.4	11.5	−9.6	−16.0	−11.1
3.0	29.7	7.8	15.8	−5.5	−11.8	−7.0
3.5	33.9	11.9	19.8	−1.8	−8.1	−3.4
4.0	37.8	15.6	23.4	1.7	−4.6	0.0
4.5	41.4	19.0	26.8	4.9	−1.4	3.1
5.0	44.8	22.3	29.9	7.9	1.7	6.1
5.5	48.0	25.3	32.9	10.7	4.5	8.8
6.0	51.0	28.2	35.6	13.3	7.2	11.4
6.5	53.8	30.9	38.3	15.8	9.7	13.9
7.0	56.5	33.5	40.8	18.2	12.1	16.2
7.5	59.1	36.0	43.2	20.5	14.4	18.5
8.0	61.5	38.4	45.5	22.7	16.6	20.6
8.5	63.9	40.6	47.7	24.8	18.7	22.7
9.0	66.2	42.8	49.8	26.8	20.8	24.6
10.0	70.5	47.0	53.8	30.7	24.6	28.4
11.0	74.6	50.9	57.5	34.3	28.3	31.9
12.0	—	54.6	61.1	37.6	31.7	35.2
13.0	—	58.0	64.4	40.8	34.9	38.3
14.0	—	61.4	67.6	43.9	37.9	41.3
15.0	—	64.5	70.6	46.8	40.8	44.1
16.0	—	—	—	49.5	43.6	46.8
17.0	—	—	—	52.2	46.3	49.3
18.0	—	—	—	54.8	48.8	51.8
19.0	—	—	—	57.2	51.3	54.2
20.0	—	—	—	59.6	53.7	56.5
21.0	—	—	—	61.9	56.0	58.7
22.0	—	—	—	64.1	58.2	60.8
23.0	—	—	—	66.2	30.4	62.9
24.0	—	—	—	68.3	62.5	64.9

Capacity and efficiency

Care 30 and Care 50 have been formulated to replace CFCs/HCFCs in existing systems. They can also be used successfully in new equipment. R600a and R290 are primarily for new equipment.

Figure 3 compares the required compressor swept volume for R600a and R12 at identical evaporating temperatures. This shows that the compressor requires a greatly increased swept volume to give comparable capacity. It would need a motor of the same size as a compressor designed to be used on R12.

Care 30 has been formulated to give capacity similar to R12. This has been confirmed by practical testing both in the laboratory and in the field by a number of engineers. In trials at the Institute of Cryogenics, University of Southampton using an automotive air-conditioning test rig, coefficients of performance of the order of six per cent greater than R12 were obtained. This and similar test work have shown that the efficiency of Care 30 is better than R12, and hence R134a. The results of the test work undertaken at the University of Southampton are shown in Figure 4. The results of tests by Bitzer comparing the performance of R290 and R22 are shown in Figure 5.

Care 50 has been formulated to give similar capacity to R22 and R502. Practical testing in both laboratory and in the field by a number of engineers has confirmed this. In trials by EA Technology using a calibrated refrigeration test rig, the performance of Care 50 proved to be comparable to that of R22. The results are shown in Figure 6.

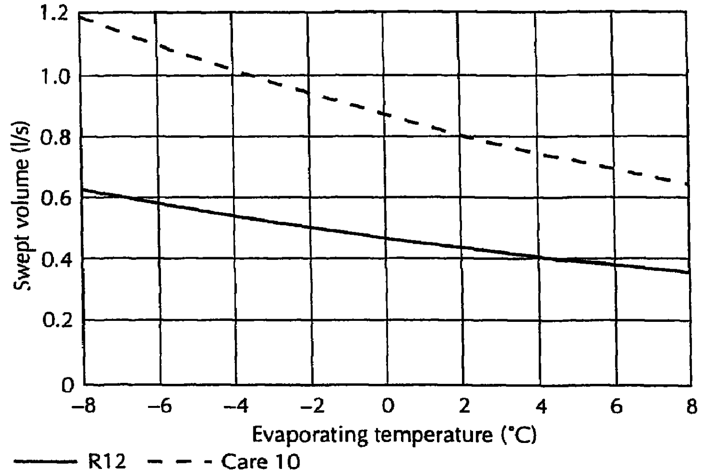


Figure 3. Comparison of compressor swept volume requirements between Care 10 and R12 at identical operating conditions

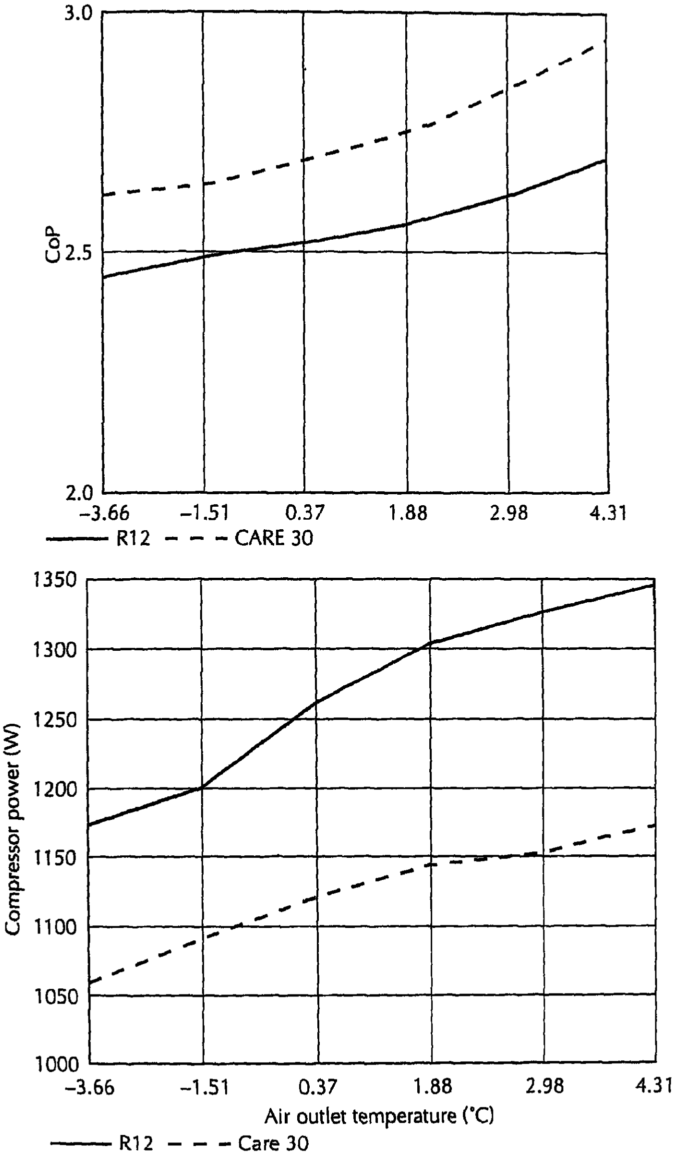


Figure 4. Data from Southampton University showing efficiency comparison of Care 30 with R12

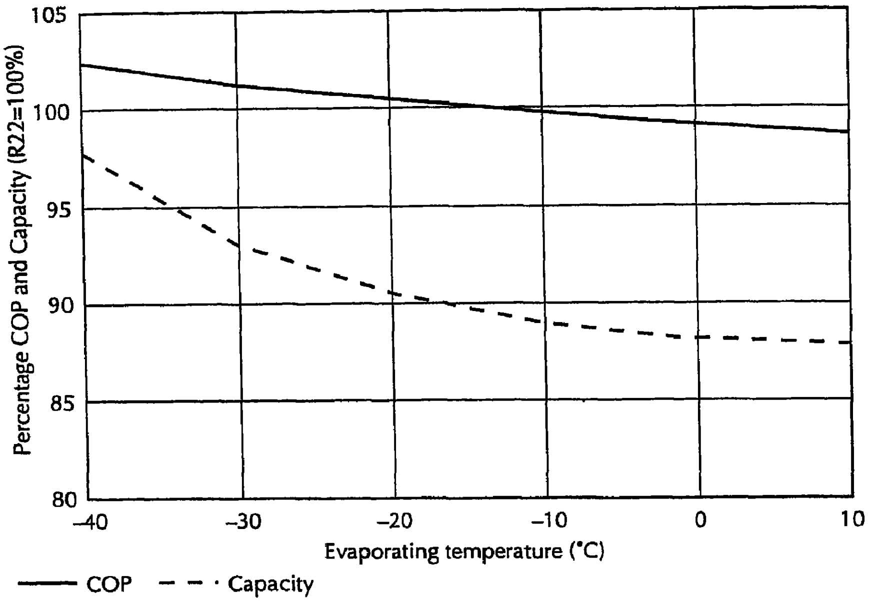


Figure 5. Data from Bitzer showing compressor performance of Care 40 against R22

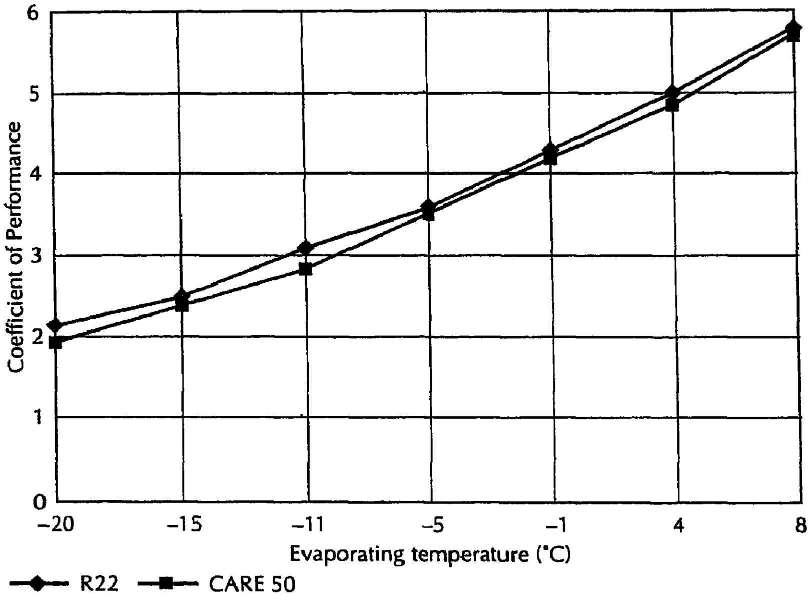


Figure 6. Data from EA Technology showing efficiency comparison of Care 50 and R22

Charge quantity

Hydrocarbon refrigerants have lower densities (but higher latent heats per unit weight and better thermal conductivities) than CFCs, HCFCs, and HFCs. In practice, this means that the charge required in weight terms is lower than that for halocarbons to give the same volumetric flow rate and the same capacity.

In general, the charge for HC refrigerants is approximately 40% that for CFC, HCFC or HFC refrigerants by weight. (This often results in cost savings). The volume of refrigerant needed is the same.

Compatibility with system materials

Hydrocarbon refrigerants are compatible with a majority of materials that would be used with traditional refrigerants, including:
- metal components;
- mineral, alkyl benzene, and ester oils;
- compressor motor materials; and
- most seal materials.

HCs are not compatible with natural rubber or silicon. It is unlikely that such materials are used in systems, but they may be used in compressor shaft seals, other seals and gaskets, solenoid valves, hoses, and charging and recovery equipment. If any doubt exists, it is advisable to contact the equipment manufacturer or supplier.

Care 30 and Care 50 are designed to be suitable for use in existing systems (although they can also be used in new systems). The compatibility of materials ensures that they can be used with minimum system modifications and by following a simple drop-in procedure.

Use of hydrocarbon refrigerants: flammability

Hydrocarbon refrigerants are flammable in the different concentrations in air (Table 5). An ignition source is also needed for combustion to occur. Potential ignition sources include:
- naked flames;
- anything at a temperature above 460 °C; and
- sparks from electrical components.

In general, Calor Gas Refrigeration recommends that the charge level in any system is related to the volume of space into which the refrigerant could leak. The recommended charges in Table 6 have been calculated from the lower explosive limit of

Table 5. Flammability limit of HC refrigerants in different concentrations in air

Flammability limit	R600a	Care 30	R290	Care 50
LFL[1] (vol. %)	1.85	1.95	2.0	2.2
UFL[2] (vol. %)	8.50	9.10	10.0	10.2

[1] LFL—lower flammability limit; [2] UFL—upper flammability limit

Table 6. Recommended charges of HC refrigerants

Room size	Room volume (m^3)	Weight of HC to reach LFL	Suggested maximum charge
2 × 2 × 2 m	8	340.0 g	70 g
3 × 3 × 3 m	27	1.1 kg	200 g
4 × 4 × 4 m	64	2.7 kg	500 g
5 × 5 × 5 m	125	5.2 kg	1 kg

the refrigerant (approximately two per cent in air by volume). If the refrigerant is evenly dispersed in the room, then the amount of refrigerant must be below the figure in the third column to prevent potential combustion. The suggested maximum charge in the fourth column is between one-fifth and one-sixth of this to provide a high safety margin and to allow for the fact that the refrigerant may not be evenly dispersed.

Electrical connections on the refrigeration system should be sealed or be of the non-sparking type, e.g. solid state. If any part of the refrigeration system is below ground, the charge should be limited to 1 kg because the refrigerant is heavier than air, and in the event of a leak, it would not be dispersed.

In general, the following guidelines should be followed:

- limit the charge quantity to the suggested maximum charge if the system is indoors with no additional safety measures; or
- eliminate ignition sources by using only sealed or non-sparking electrical components (general experience with HCs shows that problems with conventional refrigeration components are unlikely) and by eliminating naked flames; or
- use permanent atmosphere monitoring equipment designed to give an alarm if the refrigerant concentration in the air approaches LFL.

Many countries are revising refrigeration safety standards to allow the safe application of HC refrigerants. In general, the amount of charge that can be used is related

Table 7. Recommended charge amounts given in the new British Standard 4434

Occupancy category	Maximum HC refrigerant charge weight
A. Public areas, large number of people, people sleeping, etc.	1.5 kg in sealed systems 5 kg in indirect systems in special machinery rooms
B. Commercial premises, offices, etc.	2.5 kg in sealed systems 10 kg in indirect systems in special machinery rooms
C. Very few people, factories, etc. authorized access only	10 kg in humanly occupied areas 25 kg in special machinery rooms Unlimited in the open air or all refrigerant containing parts are in a special machinery room

to the information given in Table 6. Table 7 shows the recommended charge amounts given in the new British Standard 4434: 1995 (Safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems).

Refrigerant containment is traditionally very poor in commercial systems. The quality of containment can be improved (in the case of R12 and R134a, to prevent expensive environmentally damaging refrigerant escaping into the atmosphere; in the case of HCs to prevent leakage of flammable refrigerants). It can be improved by:

- using brazed joints instead of flares (brazed joints are more reliable and less prone to failure);
- using suitable flexible hose in place of copper tube for pressure switch connections (such connections are very prone to leakage, especially on the high pressure side);
- ensuring vibration transmission from the compressor is as low as possible by flexibly mounting the compressor and by using flexible pipe work connections where appropriate;
- using good quality valves and always fitting valve caps;
- leak testing (and repair where necessary) as a part of routine maintenance and CFC plant conversion.

Component selection

R600a (Care 10) has different operating conditions and hence performance to traditional refrigerants. Many hermetic compressor manufacturers now have data available for R600a.

Care 30 is similar to R12 in operating conditions and performance, so R12 data can be used to select components, including pipe sizing, for Care 30. Care 30 is miscible with mineral, alkyl benzene, and ester oils and does not require the use of an oil separator.

R290 (Care 40) may require compressors that are slightly larger than those used for R22 (or R502). Some compressor manufacturers already provide selection information for R290. The performance comparison with R22 can be used to down rate R22 capacity data for the selection of components such as compressors.

Care 50 is similar to R22 and R502 in operating conditions and performance; so R22 or R502 data can be used to select components for Care 50. Care 50 is miscible with mineral, alkyl benzene, and ester oils and should not require the use of an oil separator.

Use of Care 30 and Care 50 in existing systems

Refrigeration systems using CFCs (or HCFCs) can be converted to use less environmentally damaging refrigerants by using one of the three procedures:

- add-in;
- drop-in; and
- retrofit.

Many refrigerants could be used as 'add-ins', i.e. they are used to top up a system without removing the remaining CFC/HCFC first. This is not a recommended procedure because it renders the charge un-reclaimable. Although the charge can be recovered and cleaned, the refrigerants cannot be separated easily and, therefore, each cannot be re-used.

The term 'drop-in' could be a misnomer because the refrigerant itself requires no modifications to the system. However, some work should be done as good refrigeration practice because the system may be opened to the atmosphere. This normally includes replacing the filter-drier.

Care 30 is a 'drop-in' replacement for R12. Care 50 is a 'drop-in' replacement for R22 and R502. They can operate with the existing oil, whether it is a mineral, alkyl benzene or an ester type. Some modifications may be needed to system electrics to eliminate potential sources of ignition such as sparking electrical components.

The retrofit procedure is used where the alternative refrigerant cannot operate with the existing mineral oil. It is a lengthy and costly procedure, which must be planned in advance in order to make the necessary number of oil changes to reduce the remaining mineral oil proportion to an acceptable level.

Handling of hydrocarbon refrigerants

In many respects, HC refrigerants are very similar to traditional refrigerants. This section outlines:

- general safety considerations;
- charging; and
- leak detection.

General safety considerations

Chemical safety data sheets for Care HC refrigerant range are available from Calor Gas Refrigeration. The main points regarding safety in which HC refrigerants differ from CFC and HCFC refrigerants are highlighted below.

- They are classified as flammable gases and are flammable in concentrations in air approximately between 2% and 10% by volume.
- Small fires should be tackled with dry powder extinguishers, otherwise vacate the area and call the fire service.
- Accidental releases of large quantities of HCs can be dispersed with a water spray. The area should be evacuated (except for personnel dealing with the emergency). Sources of ignition should be isolated or extinguished. If possible, the refrigeration system should be isolated at the point of leak.

There is no occupational exposure limit (OEL) for propane, isobutane or ethane, and therefore for Care. As a guide, the OEL for liquefied petroleum gas (LPG) is 1000 ppm. This is the long-term exposure limit for an eight-hour working day, and is the same for R12 and other CFCs.

In other respects, safety considerations, which are common for CFCs, HCFCs, and HFCs, are given below.

- Contact with liquid refrigerant will cause a freeze burn (similar to frost bite), which should be treated by washing the area with cold or tepid water. Medical attention may be necessary.
- Gloves and goggles should be worn while handling refrigerant.
- HC refrigerants are heavier than air and will therefore tend to collect in pits, trenches, basements, well-type display cases/chest freezers. Such areas should be ventilated to disperse vapour.
- They will displace air and are thus asphyxiants in high concentrations. At lower concentrations, lack of oxygen will cause dizziness, nausea, increased depth and frequency of breathing and ultimately unconsciousness. The affected person

should be taken to an uncontaminated area, kept warm and at rest. Artificial respiration should be given if breathing has stopped or shows signs of falling. Medical attention should be sought.

Handling of cylinders

Guidelines for safe cylinder handling differ very little from other refrigerant cylinders and are given below.

- Do not remove or obscure official labelling on a cylinder
- Always fit the valve cap when the cylinder is not in use
- Store and use cylinders in dry, well-ventilated areas remote from fire risk
- Do not expose cylinders to direct sources of heat such as steam or electric radiators
- Do not repair or modify cylinders or cylinder valves
- Always use a proper trolley for moving larger cylinders, even for a short distance; never roll cylinders along the ground
- Use only approved cylinder accessories
- Take precautions to avoid oil, water or foreign matter entering the cylinder
- If it is necessary to warm the cylinder, use only water or air, not naked flames or radiant heaters
- Always weigh the cylinder to check if it is empty; its pressure is not an accurate indication of the amount of refrigerant remaining in the cylinder
- Do not refill the cylinders

Cylinders should be stored and transported according to local regulation for HCs (LPG).

Charging hydrocarbon refrigerants

In common with all refrigerant blends, Care 30 and Care 50 should be charged in the liquid phase to maintain the correct composition of the blend. It is important when charging a liquid into the system to take great care to ensure that liquid refrigerant does not return to the compressor. This will damage the compressor and may result in complete failure.

R600a and R290 are single substances and can be charged as liquid or gas. Before a system is ready to be charged with any refrigerant, it should be tested for safety and leak tightness, and then evacuated to remove all gases and moisture.

General charging guidelines

General guidelines to follow when charging HC refrigerants are given below.

- Always charge Care 30 and Care 50 in the liquid phase to retain the blend composition in both the system and the cylinder.
- Always use the cylinder in the upright position.

- Use hoses which are as short as possible to minimize the amount of refrigerant contained in them.
- If a large system is to be charged, the charging equipment, hoses, and system must be earthed to prevent a build-up of static electricity. In smaller systems (i.e. domestic appliances, small commercial systems, and transport refrigeration and air-conditioning applications), the flow of refrigerant will be insufficient to generate static.
- Always remove air from lines, preferably by evacuating the lines with a vacuum pump. If this is not possible, the lines can be purged, with low pressure gas if possible, or very carefully with liquid, allowing as little refrigerant as possible to escape.
- Avoid naked flames when charging, for example, there should be no smoking. Display 'No Smoking' signs.
- Have a dry powder fire extinguisher adjacent to the charging area.
- Label the system when charging is complete. The label should be prominently positioned and should state which refrigerant has been charged into the system and that it is flammable. Such labels are supplied with the refrigerant.

Charging using a charging still. When a charging still is used for Care 30 or Care 50, liquid refrigerant should be charged into the still, and the liquid taken out. Great care should be taken if the only charging connection is into the suction line of the refrigeration system. It is possible to fit an expansion device into the line between the charging still and the suction line. This could be a simple capillary tube which will evaporate the liquid before it enters the system. If R600a or R290 is used, gas can be taken out of the still.

Most charging stills measure the refrigerant by volume. The volume of HC required will be the same as that of the halocarbon refrigerant it is replacing. For example, when charging Care 30 into an R12 system, fill the charging still to the amount specified for R12 and use this amount in the system. Although the still is calibrated in weight, it is actually measuring a volume.

Charging without a charging still. When a charging still is not used, liquid can be charged into the liquid line in the normal way. If it is required to charge Care 30 or Care 50 into the suction line (for example, to top up a system or to complete the initial charging of a system), then an expansion device (for example, a capillary tube) can be used to evaporate the refrigerant before it enters the system. Alternatively, the liquid can be throttled through a manifold set.

If the refrigerant is weighed into the system, the charge of HC will be approximately 40% that of the halocarbon refrigerant it replaces. The system can be charged until the liquid line sight glass clears. However, it should be remembered that bubbles in the sight glass do not always mean the system is undercharged. They can also indicate a blockage in the liquid line filter drier or that the condenser is seriously undersized.

Beware of overcharging. Because of the smaller weights likely to be involved with HC refrigerant charges, it is possible that systems are overcharged because there is less margin for error. Great care should therefore be taken to accurately charge a small system. For example, the quantity of the refrigerants in the charging hose may be more than what is required in a domestic appliance.

Leak detection

A halide torch (or any other detector using a naked flame) must not be used to detect HC refrigerants. Electronic leak detectors will usually detect HCs, but the sensitivity may not be great enough, or may need adjusting. The leak detector should be electrically and intrinsically safe. Leak-detection fluids are suitable for use with HCs. The use of detergents with chlorine should be avoided as the chlorine may react with HCs and corrode copper pipe work. Oil additives, such as Spectroline fluorescent leak-detection system, will work with HCs. If a leak is found, it must not be assumed that it is the only one; the whole system has to be checked. If a leak is suspected from an HC refrigerant plant, all naked flames should be removed/extinguished.

Leakage from plant which has been converted from CFCs/HCFCs

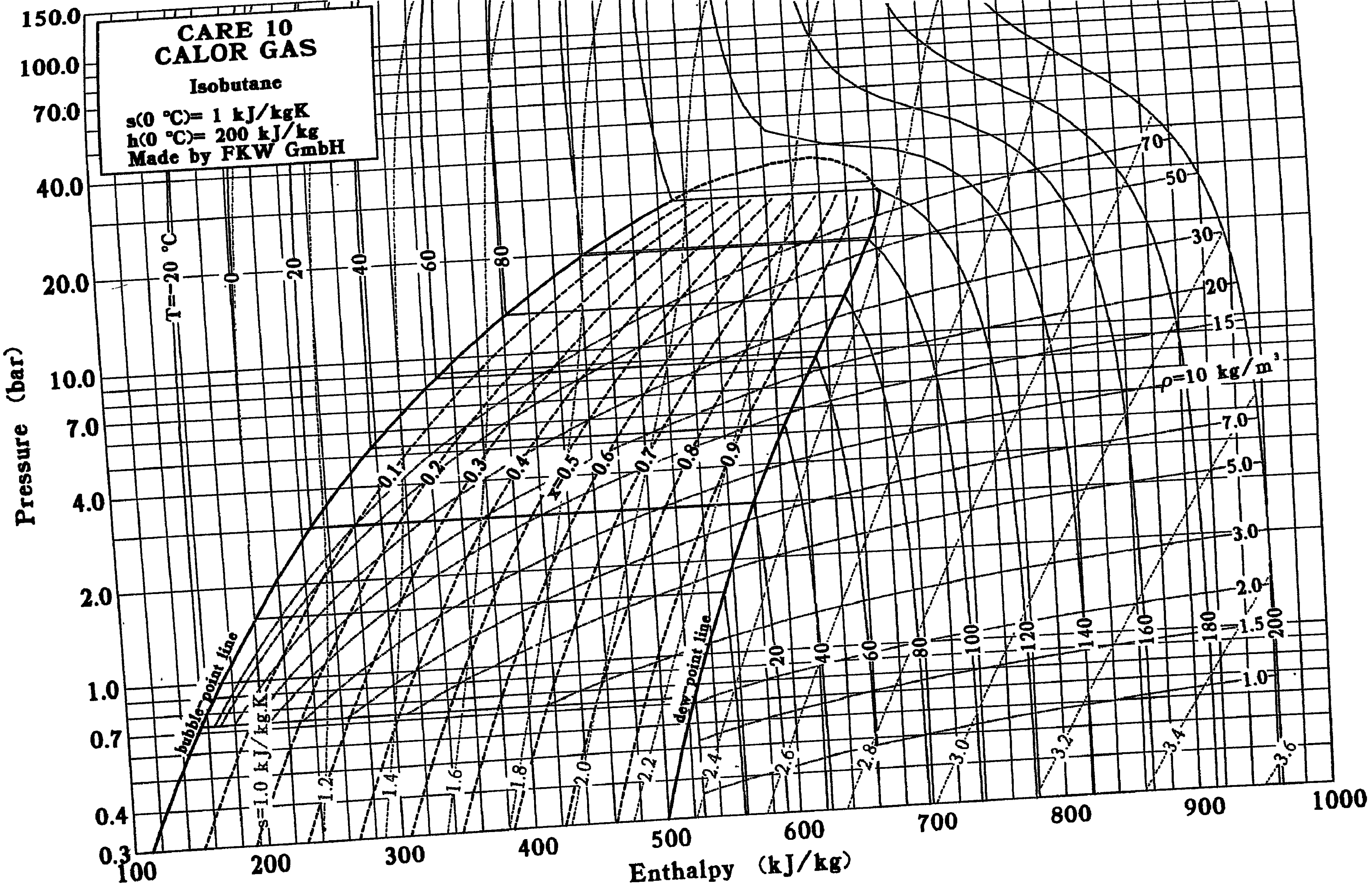
Alternative refrigerants, when used to convert CFC or HCFC plant, may sometimes leak where the old refrigerant did not. This is usually due to the different reaction with some seal materials, and also possibly due to smaller refrigerant molecule size. Such leakage may also occur with HC refrigerants (although it is less likely), so systems should be tested for leak after the refrigerant has been charged in.

Repairing leaks

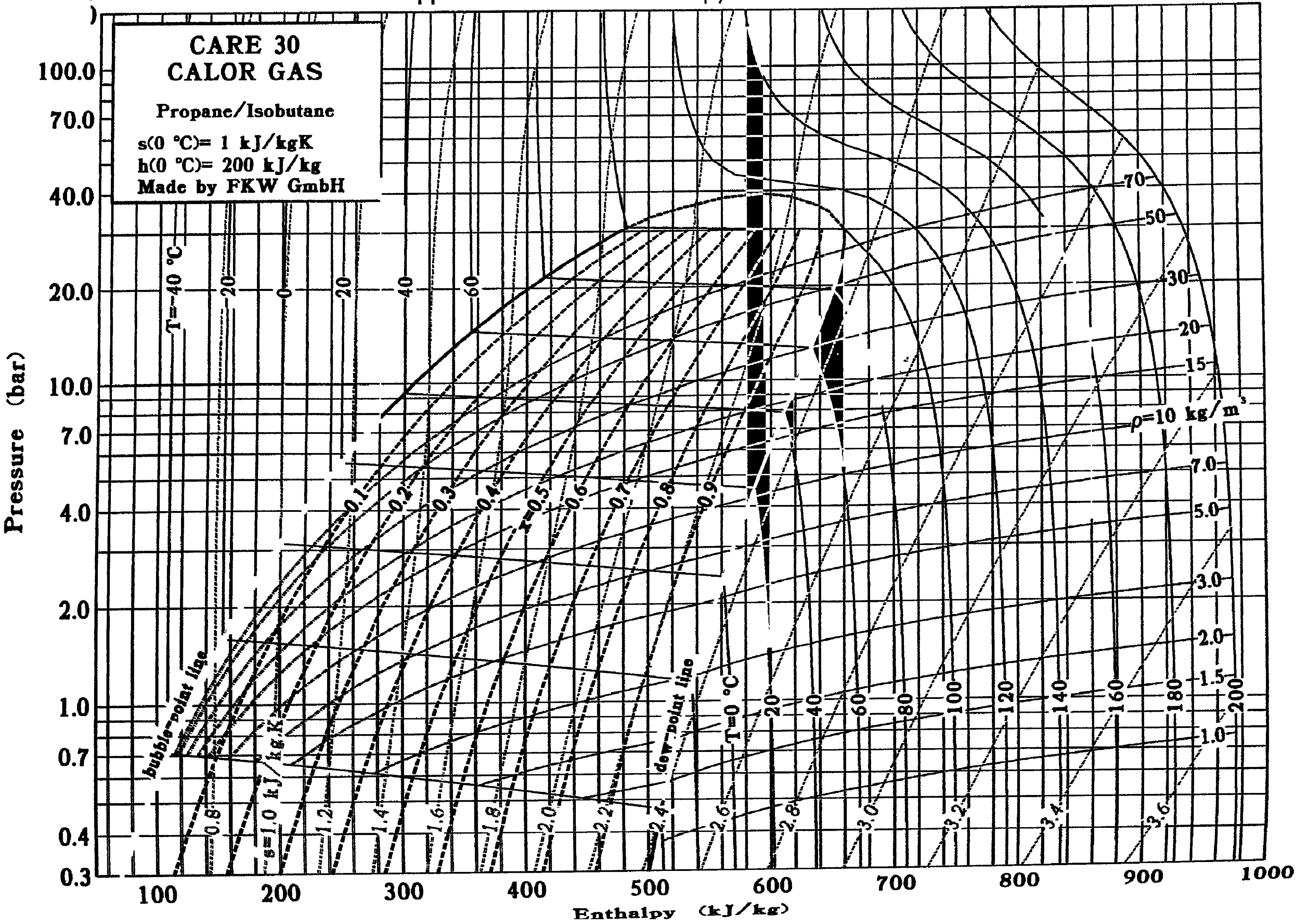
If a leak is found which requires brazing, all the refrigerant should be recovered from the plant or isolated in a part of the system remote from the leak. Dry nitrogen should be purged through the lines being brazed to prevent the formation of oxides inside the pipes; a reaction which will cause subsequent damage to the compressor. This is a good practice with all refrigerants, but the elimination of the refrigerant is particularly important with HCs.

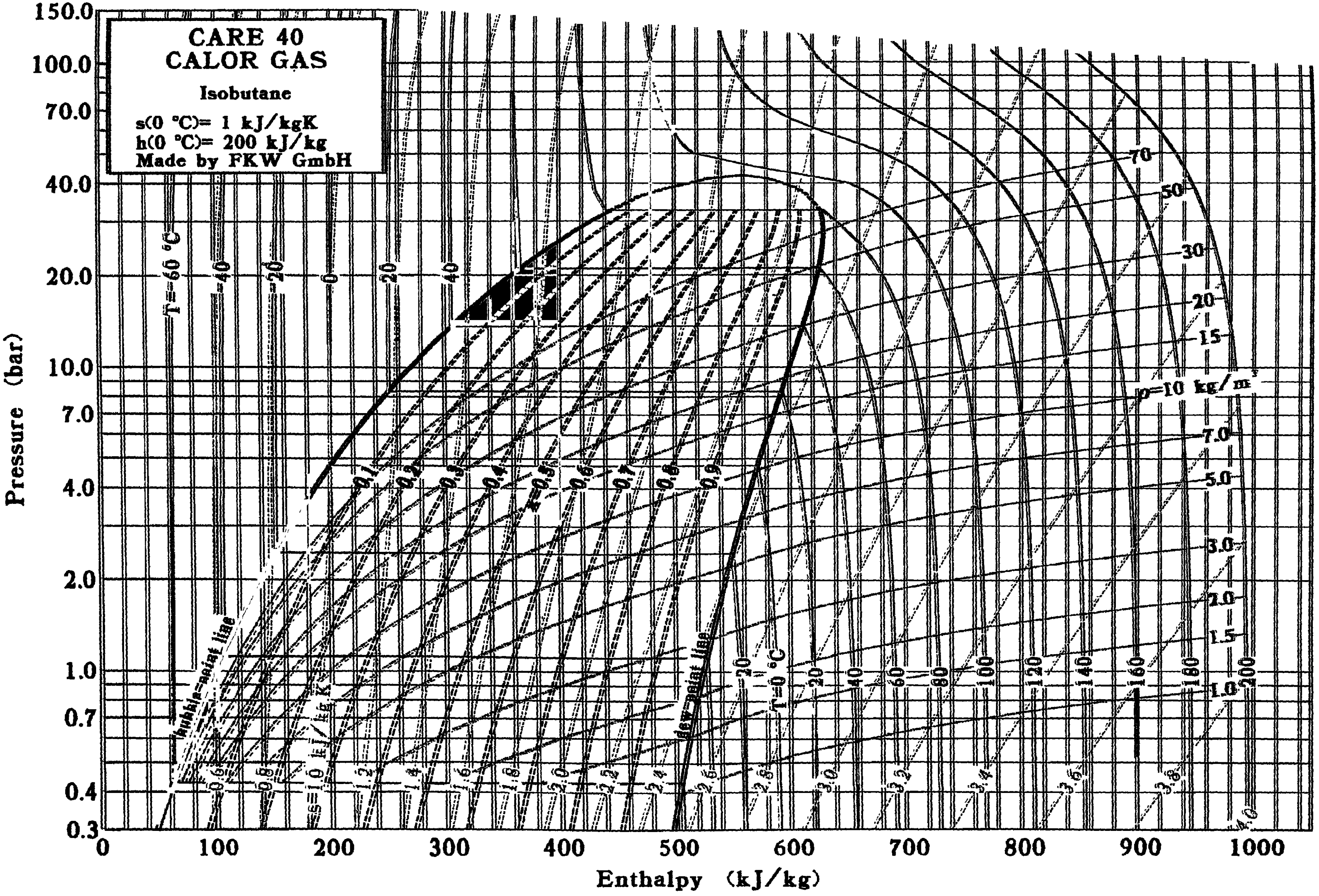
Disposal of hydrocarbon refrigerants

Care should be taken while servicing or scrapping a system. The venting of HC refrigerant will result in a potentially combustible mixture being present in the air around the system. In addition, potentially damaging oil will also escape from the system. It is dangerous to burn HC refrigerant as it is vented; this will result in uncontrolled combustion and possible toxic products from oil decomposition.

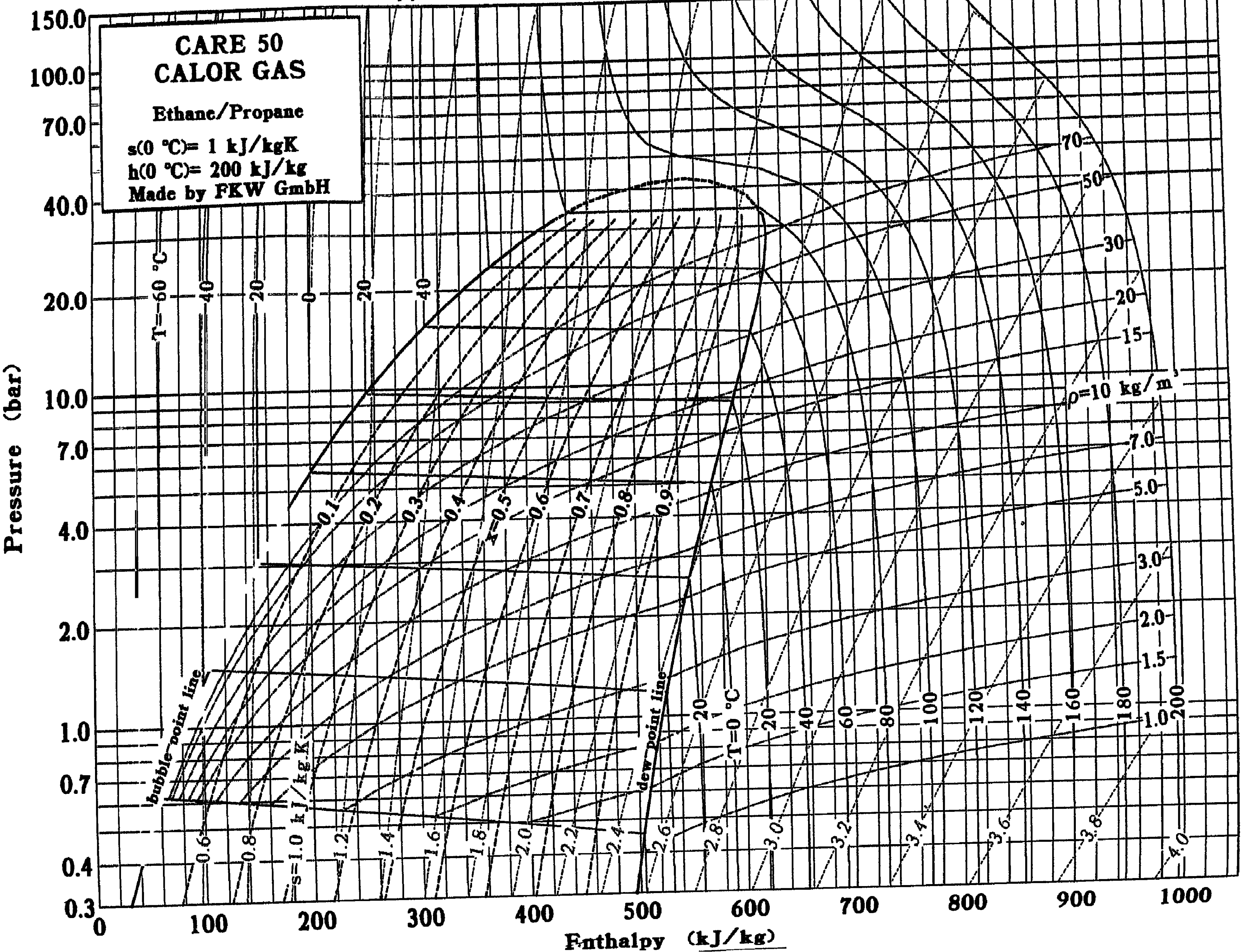
CARE 10
CALOR GAS
Isobutane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
100
200
300
400
500
600
700
800
900
1000
T=-20 °C
0
20
40
60
80
100
120
140
160
180
200
x=0.5
0.1
0.2
0.3
0.4
0.6
0.7
0.8
0.9
bubble point line
dew point line
s=1.0 kJ/kg.K
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
ρ=10 kg/m³
1.0
1.5
2.0
3.0
5.0
7.0
15
20
30
50
70

Appendix 2. Pressure–enthalpy chart for Care 30




CARE 40
CALOR GAS
Isobutane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
0
100
200
300
400
500
600
700
800
900
1000
T=-60 °C
-40
-20
0
20
40
T=0 °C
20
40
60
80
100
120
140
160
180
200
70
50
30
20
15
ρ=10 kg/m³
7.0
5.0
3.0
2.0
1.5
1.0
x=0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
s=1.0 kJ/kg K
0.6
0.8
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
bubble-point line
dew-point line

Appendix 4. Pressure–enthalpy chart for Care 50



Summary of the panel discussion on synthetic and natural fluids in domestic and commercial refrigeration

Panelists

- A S Ghoshal
- B J Wadia
- Edoardo Biscaldi
- Jack Buswell
- Jane Gartshore
- Juergen Melzer
- K Venkateswarlu
- K V N Rao
- M Srivastava
- M K Chanderasekhar
- S N Tripathi
- S Devotta
- Stephan Sicars
- V G Sardesai

Major issues

- The issues that influence the choice of refrigerant by Indian companies are availability of substitutes, cost considerations, safety aspects, energy efficiency, environmental considerations, reliability, ease of manufacturability, retrofitting, and servicing.

- Two Indian compressor manufacturers, Sriram and Kirloskar, have gone ahead with the development of compressors based on HFC134a (hydroflourocarbons) and have not considered hydrocarbons (HCs) seriously till now.
- The Indian compressor manufacturers do not mind manufacturing both types of compressors and would leave the final selection to the customer. Reference was made to a refrigerator manufacturer in USA, where both HFC134a and HC were being used side-by-side in the same plant premises.
- The flammability of HCs is a major concern. Industry should adopt safe shopfloor manufacturing practices before using HC technology. It was felt that India could learn from the experiences of European manufacturers on safe practices. A change in attitude of Indian manufacturers towards HCs is required.
- Although safety is a concern, HC refrigerants have the advantage that there are no associated compatibility problems with the lubricant and compressor parts. They could be manufactured indigenously in India with available raw materials.
- It was felt that a single changeover was an important criteria for the selection of the refrigerant.
- One manufacturer, who has already set up refrigerator manufacturing facility using HFC134a compressors, felt that the cost of the refrigerator would be much higher, since the investment for HFC134a was about three to four times higher than CFC12 (chlorofluorocarbons) technology. However, it was felt that the industry will evaluate the available options and the final decision on selection of the refrigerant would be based on economic grounds. The panelists were of the opinion that India would follow more than one route because of different foreign collaborations of Indian manufacturers.

The gist of the question and answer session is given below.

- There need not be any safety concerns regarding use of HCs in refrigerator compressors. Since the quantity of HC in a compressor is very small and similar to the quantities in aerosol cans, there need not be any safety concern as far as the consumer is concerned.
- R600a has not been found to be economically viable for commercial applications like bottle coolers and freezers because of the large size of compressors. Blends of R600a and R290 may be suitable for air-cooled units.
- Charging of HC refrigerants presents no special problems. The appliances using HC refrigerants are safe to be used under high ambient temperature.
- No special transport regulations are required for bulk transportation of HC refrigerants and the same rules as other petroleum products would apply.
- In response to a question on the suitability of HC refrigerant in open-type compressors, it was felt that HCs would be suitable if the seal is in good condition and proper ventilation is provided.

SESSION III

CYCLOPENTANE FOAM BLOWING

Properties of cyclopentane-blown foam

Mike Jeffs
Manager, International Environmental Affairs, ICI Polyurethanes, Everberg B, Belgium

Introduction

Polyurethane rigid foam has achieved almost 100% of the market share for insulation materials in household refrigerators and freezers since its introduction in Europe in the late 1950s as a replacement to other insulants, mostly fibreglass. This has been achieved because of the advantages it offers in the manufacturing process and end-product properties.

The composition of the foam has changed after that. MDI is now the dominant isocyanate and many types of polyols are being used. However, for more than 30 years, the universal blowing agent was CFC11 (chlorofluorocarbon). It gave unrivalled insulation properties and had no apparent negative features until its role in ozone depletion was realized and its phase-out proscribed by the Montreal Protocol and other national controls.

There has been a five-year period of uncertainty during which many replacement blowing agent options have been evaluated. Several hydrochlorofluorocarbons (HCFCs) have been extensively evaluated and some, notably HCFC141b, are in use. However, cyclopentane was introduced in German refrigerator factories in 1993 and has since become the dominant blowing agent in Europe and its use is spreading rapidly to both developed and developing countries worldwide. This acceptance is based on its environmental properties of zero ozone depleting potential (ODP) and very low global warming potential (GWP), which offer the manufacturers of appliances a period of stability. The technology offers a one step change to a durable solution and where developing country enterprises can learn from the experience of those in developed countries.

This paper describes the properties of cyclopentane-based foams in comparison with CFC11 and with other options. It also indicates that precautions must be taken because of the flammability of cyclopentane. These precautions are described in detail elsewhere (see Gardner in this volume). It is also made clear that the technology is still evolving and there will be improvements in the properties of cyclopentane-based foams and refinements in the composition of the blowing agent itself. The application of vacuum panels and the potential use of liquid hydroflourocarbons (HFCs) will also be discussed.

Technical requirements of polyurethane rigid foams and blowing agents

Modern refrigerators and freezer designs rely heavily on the properties of the insulating foam which is, in turn, dependent on the characteristics of the blowing agent.

The prime requirement is to provide long-term insulation to reduce the energy consumption of the appliance while maintaining the contents at the required temperature and to prevent moisture condensing on its outside surfaces. The foam also provides strength and dimensional stability to the structure allowing the use of thinner guage steel and plastic (liners) with considerable cost and weight savings. These properties must be long-lasting so that the appliance has a useful life of 20 years or more.

The processing properties of foam are cridical in the cabinet manufacturing stage. The reacting foam has to flow throughout the cabinet in a minimum time so that product quality and production rates are maintained. This short statement indicates the critical technical aspects for the evaluation of any new foam technology such as the one based on a different blowing agent. These are complementary to requirements of safe operation in the factory and meeting contemporary environmental standards.

Blowing agent options

The principal characteristic of blowing agent options that are considered by appliance manufacturers and their suppliers during the CFC replacement programme are shown in Table 1.

In traditional technologies, CFC11 has been used at concentrations of between 12% and 17% by weight of the polyurethane foam chemicals. Technologies in Europe and those based on European technologies used concentrations in the range of 12%–14% by weight. In North America and Japan, concentrations in the range 15%–17% were the norm in order to optimize insulation values. Most developing

Table 1. Characteristics of blowing agents

Characteristics	CFC11	HCFC22/ HCFC142b	HCFC141b	HFC134a	Cyclo-pentane
Chemical formula	$CFCl_3$	$CHClF_2/CH_3CClF_2$	CH_3CCl_2F	CH_2FCF_3	$(CH_2)_5$
Molecular weight	137	86/100	117	102	70
Boiling point (°C)	24	−41/−10	32	−27	50
Gas conductivity (mW/mK at 10 °C)	7.4	9.9/8.4	8.8	12.4	11.0
Flammable limits in air (vol. %)	None	None/ 6.7–14.9	7.3–16.0	None	1.4–8.0
TLV or OEL (ppm)	1000	1000/1000	500	1000	600
ODP	1.0	0.055/0.065	0.11	0	0
GWP (100 year ITH)	3400	1700/2000	630	1300	3

country technologies are of European origin, hence using CFC concentrations at the lower end of the range.

The reduced CFC technology option is normally based on a CFC11 concentration of six to seven per cent by weight. The common definition of <2.5 g/l equates to 7–7.5 per cent by weight CFC11. Reduced CFC technology is based on increasing the amount of CO_2 co-blowing by increasing water level in the formulation. This gives increased CO_2 generation through the water-isocyanate reaction. This technology has been a useful interim measure but is now outdated because of the availability of cyclopentane and other technologies.

The mixed HCFC22/HCFC142b option has been developed to counteract the comparatively rapid foam thermal conductivity ageing characteristics of HCFC22, if used alone, and is normally used at a 40:60 molar ratio. This ratio negates the flammable nature of HCFC142b. This option is used by very few manufacturers, and some in Europe, as an interim step.

HCFC141b has been a leading contender and is widely used in North America. Its comparatively high ODP of 0.11 has resulted in its replacement in other areas by cyclopentane. This is despite its good initial thermal conductivity.

HFC134a was used for a short time in Europe before being replaced by cyclopentane.

The use of carbon dioxide alone is not viable for domestic refrigerators and freezers because of a comparatively high initial foam thermal conductivity, which itself would require unit redesign, and, more importantly, the rapid ageing of the foam, even with the protection of plastic liners, to wholly unacceptable values.

Cyclopentane foam properties

Polyurethane rigid foam systems designed for use with cyclopentane are now available from several suppliers although, arguably, the most highly developed are available from the main European suppliers who have been operating in that highly competitive market. Hydrocarbon (HC) foam technology is comparatively new and is still evolving. The main development areas are given below.

- *Reduction of foam density*. The first cyclopentane foams to be commercialized had to have a foam density (up to 15%) higher than that had been used with CFC11-based foams. This has imposed a considerable cost penalty due to the solubility of cyclopentane in the foam matrix causing a loss of mechanical strength. This had to be compensated by increasing the foam density to ensure freedom from foam shrinkage. The development routes include optimization of the foam strength through choice of polyol structure and the modification of the blowing agent to include n- or iso-pentane in a blend or, more radically, replacement of cyclopentane by n- or iso-pentane blend. The latter solution has a negative effect on thermal conductivity, at least, at temperatures of 10 °C or higher.
- *Reduction of thermal conductivity*. Table 1 indicates that the vapour thermal conductivity of cyclopentane is higher than that for CFC11. In fact, all the alternatives are inferior to CFC11 in this respect. This effect is transposed through the thermal conductivities of the respective foams. Various routes exist to ameliorate this effect. These include the optimization of cell structures to obtain smaller cells and hence reduce the transfer of heat by radiation.

  The related phenomenon of the condensation of cyclopentane at low temperatures can affect the thermal conductivity of the foam at lower, for example, freezer operating temperatures. This, in turn, can be ameliorated by using blends with iso- or n-pentane, which can increase the vapour pressure in the cells.

A range of foam systems are available to meet the needs of manufacturers of domestic appliances. Table 2 lists the formulation and key parameters of three cyclopentane-based systems in comparison with 'controls' based on CFC11, reduced CFC11, and HCFC141b. Table 3 lists the foam properties of the same systems.

The data displayed are for commercially-used formulations. The three cyclopentane-based systems are optimized for:

- thermal conductivity (Formulation 4);
- demould time (Formulation 5); and
- low density (and low viscosity) (Formulation 6).

These effects are evident in the properties displayed in Tables 2 and 3. Formulation 4 has a foam initial thermal conductivity only three per cent above that of

Table 2. Foam systems – *formulation and processing parameters*

								Brett 200'20'5 cm		
			Blowing		Reaction times (seconds)			*Free rise*	*Minimum*	*JDT 10%*
Formulation no.	Blowing agent	Polyol (Pbw)	agent (Pbw)	Isocyanate (Pbw)	*Cream*	*String*	*Tack free*	*density (kg/m³)*	*fill (kg/m³)*	*OP, 4 min (mm from 50)*
1	CFC11	100	26	126	7	53	75	20.6	29.6	50.9
2	Reduced CFC11	100	15	140	5	45	70	22.0	31.0	50.8
3	HCFC141b	100	18.7	154	9	65	105	22.4	34.2	50.9
4	Cyclopentane	100	11	135	5	43	68	25.0	35.0	50.8
5	Cyclopentane	100	12	161	5	45	70	25.0	35.5	50.5
6	Cyclopentane	100	13	138	5	40	58	22.6	33.5	50.7

Table 3. Foam systems – typical foam properties

Formulation no.	Blowing agent	Average core density (kg/m³)	Thermal conductivity at 10°C (mW/mK)	Compressive *strength at* 10% (kPa)	Dimensional stability		Closed cell content (%)	Cell size (μm)
					–25 °C (% vol.)	*+100 °C (change)*		
1	CFC11	28.5	17.7	150	<1	<1	95	250
2	Reduced CFC11	32.0	19.0	149	<1	<1	94	238
3	HCFC141b	35.9	19.2	180	<1	<1	95	180
4	Cyclopentane	36.8	19.6	234	<1	<1	96	170
5	Cyclopentane	37.0	20.0	241	<1	<1	96	182
6	Cyclopentane	35.1	20.2	185	<1	<1	95	180

Formulation 2 (reduced CFC11) which it is designed to replace. Formulation 5 shows, through the Brett mould data, curing or jig dwell time performance equal or superior to those of CFC11-based formulations. Formulation 6 shows a step in the reduction of the foam density with a density increase of just under 10% relative to that of the reduced CFC11 formulation, compared to a density increase of 15% for Formulations 4 and 5.

The HCFC141b-based formulation shows the low foam initial thermal conductivity in keeping with its vapour phase conductivity being closest to that of CFC11.

The above properties were obtained with 'pure' grade cyclopentane (>95% cyclopentane). Experience has shown that the difference in overall performance with 'technical' grade cyclopentane (about 70% cyclopentane) is very small. The change in thermal conductivity is typically less than 0.5 mW/mK.

Ageing phenomena

Domestic refrigerators and freezers should have a service life of 20 years or more. Unit failure caused by foam defects could arise from either loss of insulation value or shrinkage/dimensional instability. These faults could take 10 or more years to manifest themselves – a far longer time-scale than can be afforded when meeting an environmental challenge such as CFC11 replacement.

Rapid diffusion of the blowing agent can cause these failures. Some alternatives, notably CO_2 plus HCFC22, are known to diffuse rapidly out of the foam and also, possibly, through the ABS or PS inner liner. For the other blowing agents, it is not easy to differentiate. Accelerated ageing studies of uncovered cyclopentane-based foams show that the ageing phenomenon is of the same time-scale as CFC11 and, although the initial thermal conductivity is typically up to one mW/mK higher than a reduced CFC11 foam, this difference has disappeared after four to five weeks ageing at 70 °C (Bazzo 1995). In turn, CFC11-based foams have been proven over many years of practical service.

There is also a discussion over the amount of ageing over the lifespan of a practical appliance in service. One study indicated that the upward drift for CFC11-based foams in appliances does not exceed 4 mW/mK (World Bank 1994). Another study of foams extracted from appliances after use for up to nine years gave thermal conductivities in the range 16.8–18.1 mW/mK (measured at 0 °C) for CFC11-based foams. These are effectively initial thermal conductivities (Jeffs *et al.* 1983). Based on this analysis and comparison, cyclopentane-based foams are found to be extremely durable.

Plastic liner interactions

The strong solvent effect of HCFC141b on PS or ABS liner plastics was effective in prolonging the development time before implementing the systems in North America. The solutions, while varying with appliance design, have necessitated modifications in the base plastics or the use of barrier layers incorporated into composites. This results in significant additional costs, which will be displayed later.

In contrast, experience with cyclopentane-based foams has shown that the standard plastics developed for use with CFC11 are suitable for use with the HC solution.

Energy consumption comparisons

While laboratory measured thermal conductivities give an indication of relative energy consumptions, reliable data can only be obtained from tests of assembled cabinets during use. An average increase in energy consumption of up to 3.5% has been quoted in one study (World Bank 1994). A recently published paper has compared cyclopentane-based system with other systems, relative to reduced CFC11 (Table 4) (Kee Bong Lee *et al.* 1995)

This confirms that the thermal conductivity of the foam can only be used as a guide and that the energy consumption of cyclopentane-based foam insulated appliances are only slightly above that for reduced CFC11-based units. This small change in energy consumption has been compensated for by, at the most, modest changes in unit design.

Equipment changes and safety measures

Due to the generally inferior thermal insulation properties of all the CFC11 alternatives, the use of high pressure polyurethane processing equipment is preferred as it contributes to improving the foam structure.

Table 4. Thermal conductivity and energy consumption

Parameters	Reduced CFC11	HCFC141b	Cyclopentane
Thermal conductivity	100	98.6	107.6
Energy consumption	100	98.0	102.0

The main changes necessary with the principal alternatives are listed in Table 5. With HCFC141b-based technology, there is a necessity to consider the liner processing step. For cyclopentane-based technology, there has to be a professionally conducted audit of the safety precautions for both the trial and production stages. The necessary changes are now well established and expert guidance is available from many sources. In addition to converting the processing equipment and the door and cabinet moulds and jigs, there are two other important aspects to be highlighted.

There should be safe delivery and storage facility for the bulk cyclopentane. The use of drums with the necessary frequent handling should be avoided. Ideally, there should be bulk tanker deliveries to an underground storage facility, which is located outside the factory wall.

There must be an emphasis on training of all personnel involved with the process so that accepted procedures are understood and followed. The factory management should arrange for periodic audits of the operating procedures.

Table 5. Equipment changes

Alternative	Polyurethane processing	Refrigerator jigs/moulds	Sheet extrusion	Liner vacuum forming
Reduced CFC11	None	None	None	None
HCFC22/HCFC142b	High pressure equipment plus pressurized blowing agent equipment	New jigs for thicker walls may be necessary	None	None
HCFC141b	Leakproof blowing agent blending	None should be necessary	Depending on grade of HIPS or ABS technology, new equipment may be necessary	None
HFC134a	As for HCFC22/ HCFC142b	As for HCFC22/ HCFC142b	None	None
Cyclopentane	Precautions to avoid explosive atmospheres	Precautions to avoid explosive atmospheres	None	None

The flammability issue relates to the handling of the bulk HC and the polyol blend containing it. There is no relevant effect on the foam or the appliance itself.

Cost comparisons

In comparing the costs of implementing the technologies to replace CFC11 in foams, the two main factors are the capital costs to convert the manufacturing plant to operate safely with flammable cyclopentane on the one hand, and the increased costs of more sophisticated plastic liners necessary for use with HCFC141b on the other.

A study in Korea has given the following comparison of costs which include those associated with the foam, the plastic liner, and the capital investment (Kee Bong Lee *et al.* 1995). These are illustrated in Table 6 relative to reduced CFC11 technology.

In the context of conversion of refrigerator and freezer factories in developing countries and the financing of these conversions by the Montreal Protocol Multilateral Fund, a study of the relative costs of implementing the various options in a factory producing 200 000 units per annum was undertaken (World Bank 1993). The results are expressed in terms of a unit abatement cost (UAC), which is the cost to replace a unit of ODS. The results are shown in Table 7.

The range of UACs for HCFC141b projects reflects the various plastic liner technology options.

These studies are in agreement that cyclopentane provides the most cost-effective overall option. Furthermore, the conversion to HCFC141b technology may result in additional costs to subsequently replace it by a zero ODP technology. While

Table 6. Total cost comparisons

Reduced CFC11	100.0
HCFC141b	120.8
Cyclopentane	110.1

Table 7. Cost comparisons, CFC replacement

$/kg/year	Reduced CFC11	HCFC141b	Cyclopentane
UAC	0.87	5.45–15.56	2.62

cyclopentane is typically 55%–70% of the price of HCFC141b (per kg) and less is used in a formulation, the potential saving can be negated by the greater use of other components. Foam cost contributions are strongly influenced by the density changes discussed earlier.

Future developments

It would be naive to expect insulation technology development to plateau out in the next decade. In addition to the programmes to refine the HC (including cyclopentane) technology described earlier, there are other relevant developments in progress.

Driven by the need to reduce energy consumption and increase effective internal volumes, the use of vacuum insulation panels are being actively considered and are in production in some cases. Most of these technologies replace part of the normal polyurethane rigid foam with panel whose thermal conductivity is up to four times less than that of the foam. The energy consumption of the cabinet may then be reduced by, typically, 20%. There are several contending technologies based on silica particles, glass fibres or microcell (open-celled) polyurethane foam. Specially developed encapsulating foams based on cyclopentane are available to use with these products. They are optimized to flow well in the cavities within the refrigerator walls which are constricted by the inclusion of vacuum panels.

A second development is that of liquid HFC blowing agents. These are being evaluated for making it commercially available by the year 2000. The main characteristics of these blowing agents and the results of early evaluation in US refrigerator systems are shown in Table 8 in comparison to HCFC141b.

Table 8. Liquid HFC blowing agents

Parameters	Unit	HFC245 fa	HFC356 mffm	HCFC141b
Molecular weight	—	134	166	117
Boiling point	°C	15.3	25	32
GWP	100 year ITH	820	1160	630
Flammability limits in air	%	None	7.3–9.6	7.3–16.0
Foam thermal conductivity at 10 °C	mW/mK	17.7	17.7	17.3
US Department of Electronics energy consumption	—	100.9	103.7	100

There are many aspects, including costs and toxicology, to be evaluated. Their effective contribution to climate change is also being studied by application of total equivalent warming impact (TEWI) analysis.

Market trends

Cyclopentane-based technology was introduced into refrigerator and freezer production in the Spring of 1993 and is now used by almost all (95%) European manufacturers. Several million appliances are now in use. The technology has also been rapidly implemented by manufacturers in Australia and New Zealand.

As stated, appliance manufacturers in North America (principally the USA) have converted to HCFC141b. This blowing agent will be phased out by the end of 2002 under the Clean Air Act and manufacturers are intensively evaluating alternative technologies which are both zero ODP and help to meet even more stringent regulations on energy consumption of appliances.

Japanese manufacturers and their transplants in developing countries have used or considered HCFC141b and HCFC22/HCFC142b technologies, but many are now using or planning to convert to cyclopentane.

Numerous developing country enterprises have converted to cyclopentane or have active programmes to do so. It should be noted that factories, which are capable of operating with cyclopentane, are already equipped to use the refined HC blowing agent technologies that are being introduced or other foam technologies under development.

Conclusion

Rigid polyurethane foam technology based on cyclopentane is now well proven and in wide-scale use. It provides an environmentally acceptable solution while fulfilling all the complex technical demands for an insulating foam in a stringent application.

Acknowledgements

The author gratefully acknowledges the assistance of several colleagues in ICI Polyurethanes and of Dr W Bazzo in particular.

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Manufacturing equipment for pentane-blown foams for refrigerators and panels

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Introduction

The replacement of CFC11 (chloroflourocarbon) with cyclopentane as an expanding agent in rigid polyurethane foams for insulation applications – mainly for domestic and commercial refrigerators and freezers – is an accomplished task today. Being in industrial production in various countries since April 1993, this process has passed various tests quite easily. Industrial feasibility production, safety, foam's dimensional stability, and insulation capacity have all been widely demonstrated in several million refrigerators manufactured and sold worldwide.

While the research continues for the definition of an industrial process for manufacturing domestic refrigerators complying with forthcoming energy-saving laws, cyclopentane-blown foams seem to represent the transition solution (for this application) for the next decade.

Market survey

Europe

The conversion of existing plants and the installation of new, dedicated ones have attracted all the major groups in Western Europe, former USSR, Poland, Hungary, and Czech and Slovakian republics.

North America

North America still does not use cyclopentane, and prefer HCFC141b (hydrochlorofluorocarbon) because of its higher insulation performance and easy use. This interim solution seems to be perceived as long-term, until a new technology – more energy compliant – is introduced. Some manufacturers have installed one lab-machine in their R & D centres to evaluate cyclopentane; but none of them have moved to production so far.

South America

Partly due to the World Bank action in assisting the developing countries in their CFC phase-out programme, and partly because of the increasing unavailability of CFC11-blown formulations, major South American manufacturers have specified all their new plants for using cyclopentane. Argentinian and Brazilian producers may start their conversion by 1996, while the other countries are expected to follow soon.

Africa

Plants, which are able to work with cyclopentane, have been ordered for Egypt, Morocco, Algeria, Tunisia, and Cameroon with the help of United Nations Industrial Development Organization (UNIDO).

Australia and New Zealand

In Australia and New Zealand, the market is shared by three major suppliers, and there are two or three factories already in production with cyclopentane.

Asia

Japan does not seem to be the right country for this explosive blowing agent. Local regulation on flammable chemicals would imply extrémely high costs of conversion. However, several cyclopentane-capable lab-machines and some manufacturing lines for small production series have been supplied. China is moving towards cyclopentane, with assistance from United Nations Development Programme (UNDP) and UNIDO; a number of new, dedicated plants have been ordered recently. As far as retrofitting of existing units is concerned, we know of current negotiations only, with no decisions taken yet.

All South Korean producers will have some cyclopentane-capable lines in production by 1995. In Thailand, one plant was ordered and should be in operation by now. In Malaysia and Indonesia, negotiations are currently being held under UNDP supervision. Several negotiations are also being held in India, Pakistan, Gulf Emirates, Iran, Syria, and Jordan.

As we have seen, the situation varies according to the geographic area. The trend is not clear, especially in those countries where, together with the CFC substitution programme, an energy-saving legislation discusses the use of vacuum foams as insulating media. The use of vacuum panels, a technically attractive solution, seems to be destined to upper-class refrigerators only due to their cost.

As a matter of fact, the successful installation of more than 100 plants (from our group only) confirmed the following provisions.

> The safety measures suggested in the very beginning of this technology were proper and correct. The use of specific pre-blending stations, storage tanks, metering machines, foaming fixtures and related ventilation equipment, gas monitoring networks, and electric safeties has prevented explosions and accidents. The careful use of ventilation – a good way in every plant for polyurethanes – reduces the risk of accumulation of cyclopentane gas in those areas (premixing and polymerization) where little amounts of cyclopentane could be emitted regularly. In order to understand better the evaporation behaviour of pentanes when blended with polyols, a subject about which no literature has been produced yet, Cannon committed a specific research to the Italian authority in charge of testing hydrocarbons (HCs) and combustibles. A special equipment was manufactured to test evaporation of blends made with variable percentages of cyclopentane and conventional polyol for refrigerator manufacturing (Figure 1).

Results of the test highlighted the fact that a polyol blend containing 15% of cyclopentane shows an evaporation rate of 80 g/m^2 per hour. The same test performed on pure cyclopentane gives a result of 4610 g/m^2 per hour. Therefore, a commercial blend of polyol and cyclopentane shows an evaporability rate equal to 1.73% of the pure HC. This low figure allows to take into consideration the amount of pure cyclopentane only, and not the total blend's, when calculating the quantities present in the production area and in storage. The repeatability of the process is proven. Dedicated equipment has been designed to mix cyclopentane with polyols in desired, programmable percentages.

Figure 2 shows a typical production report of an EasyFroth premix unit used at a major manufacturer's site in Northern Italy for blending the polyol of a cabinet foaming

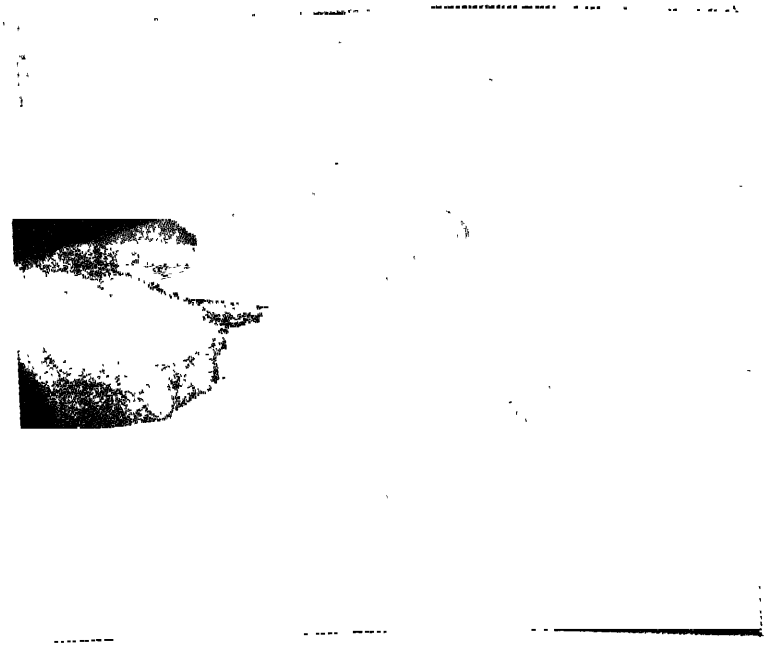


Figure 1. Testing equipment for pentane evaporability

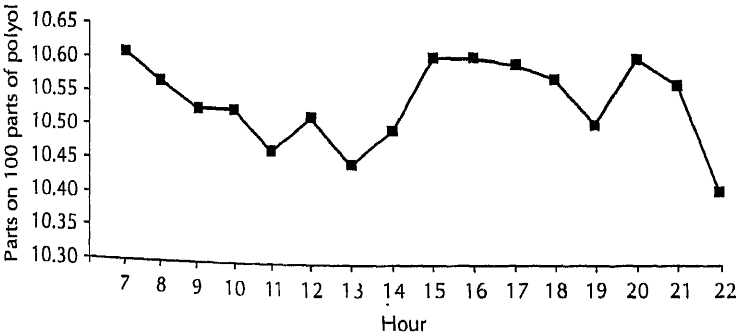
plant. These blending stations usually work unattended, automatically preparing batches of blended polyol when one of the day-tanks sends a request for a new batch.

In large plants, they have been installed in specially built rooms, where all electric components are mounted in one room and all the parts in contact with cyclopentane are in the contiguous one, totally explosion proof (Figure 3).

As we see in Figure 2, in all the batches, the cyclopentane percentage remains within ±1% of the set value. Foam's performances are improving. Compared with earlier formulations, significant success has been achieved. Flowability has reached satisfactory levels through the optimization of liquid laydown and filling patterns. Insulation factor measured in real-life conditions, i.e. calculating the energy consumption of various models is equal to that of Freon-reduced formulations.

Dimensional stability is within acceptable limits, partially helped by a slight increase in moulded density and overpacking to optimize foam's isotropy.

Commercial refrigerators have gone from a traditional 32–33 kg/m^3 density for CFC11-blown foams to 36–37 kg/m^3 for cyclopentane-blown ones. This increase does not influence the design of polymerization jigs manufactured to withstand even higher pressures. Demoulding time is a parameter deriving directly from foam's dimensional stability and its moulded density and overpacking ratio, and is also



Hour	Parts
7	10.61
8	10.57
9	10.53
10	10.53
11	10.47
12	10.52
13	10.45
14	10.50
15	10.61
16	10.61
17	10.60
18	10.58
19	10.51
20	10.61
21	10.57
22	10.41

Figure 2. Production report of an EasyFroth premix unit for blending the polyol of a cabinet foaming plant (cyclopentane percentage in polyol blend: cabinet no. 2, 8 July 1994)

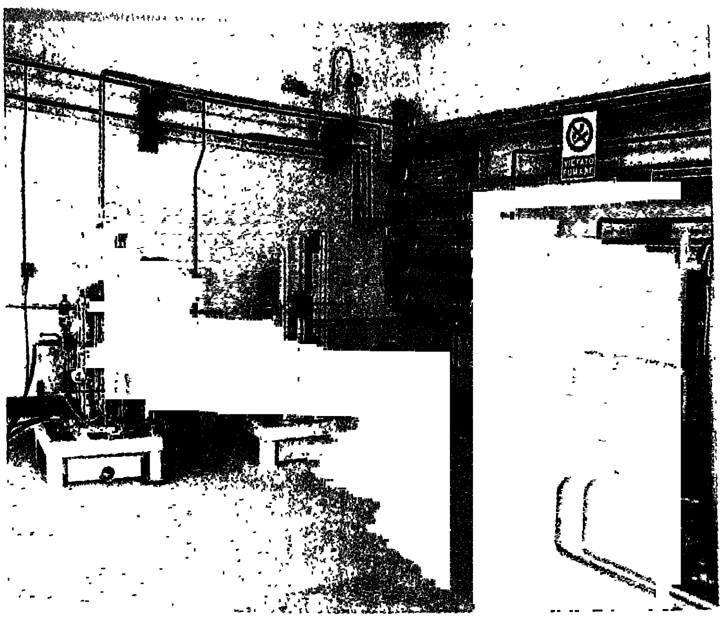


Figure 3. Explosion-proof room dedicated to polyol/cyclopentane premixing operations

affected by the market requirement for thicker walls. All the values of the above-mentioned parameters worsened in the early days and cyclopentane-blown foams needed longer demould times. It has been recently reported that formulation adjustments have brought back the demould times to 3.5' for 50–60 mm thick freezers and to 7' for 100 mm thick ones. Shorter demould times seem to be out of target for the time being.

New technological requirements

The introduction of cyclopentane in polyurethane foams modified some habits in the manufacturing of refrigerators. Equipment for storing and premixing cyclopentane had to be added, metering equipment and foaming fixtures had to be adapted or replaced. Not all manufacturers have the same problems; different products, different manufacturing habits, and local legislations deeply influence the choice of production equipment.

Four basic scenarios that characterize this industry are given below.

1. Manufacturers of domestic refrigerators and freezers working with a few models in large numbers do not require frequent model changes. Formulations are never modified and polyol/cyclopentane blends can be prepared in big batches in special rooms, and stored in day tanks that feed several metering units through a pipework.
2. For manufacturers of small–medium refrigerators, a model change often means a different foam density. This implies the preparation of smaller, precise amounts of polyol/cyclopentane blend, as often as they are required by the foaming machine; installation of one blending equipment as a back-up to each metering unit, to the advantage of modularity and production flexibility.
3. For manufacturers of large refrigerators and freezers for commercial applications (supermarkets, restaurants, ice cream parlours, bars), the production is less; but quantities of foam injected are relevant with a proportionally high amount of cyclopentane emitted per shot. Danger of accumulation of cyclopentane vapour is high, especially if polymerization jigs are scattered on a large assembly hall.
4. Producers of sandwich panels used for refrigerated cells and walk-in coolers, characterized by large panel presses, find it difficult to enclose ventilated boxes, therefore emit large quantities of cyclopentane vapours per injection.

Solutions

Cannon has supplied cyclopentane-compliant foaming equipment to more than 60 different customers in the world. The available solutions to solve the problems seen above are listed below with examples.

- *Pentane storage stations.* Pentane storage stations are built above ground where there are no buildings, roads or railways nearby. This solution can be easily inspected and maintained, and supplies a very good feeding to the cyclopentane feeding pump.

  The underground storage solution is necessary when the above safety conditions cannot be met, or when the external temperature drops several degrees below 0 °C. It allows for an easy gravity-unloading from road-tankers, but requires more attention for the transfer of cyclopentane to the foaming plant, and is slightly more complex as far as maintenance and inspection are concerned.

  Cannon, upon requests of customers, has supplied until now either the engineering drawings for making a proper storage station, or the specific equipment excluding the tank, or the full installation.
- *Multi-EasyFroth.* Multi-Easy Froth is a high-pressure pre-blending unit to prepare mixtures of polyol and cyclopentane or low boiling-point blowing agents (LBBA), with electronically controlled ratio and ventilated safety box (Figure 4).
- *Penta-EasyFroth™.* Penta-Easy Froth™ is a high-pressure pre-blending unit specifically designed for cyclopentane and other liquid-blowing agents (also available

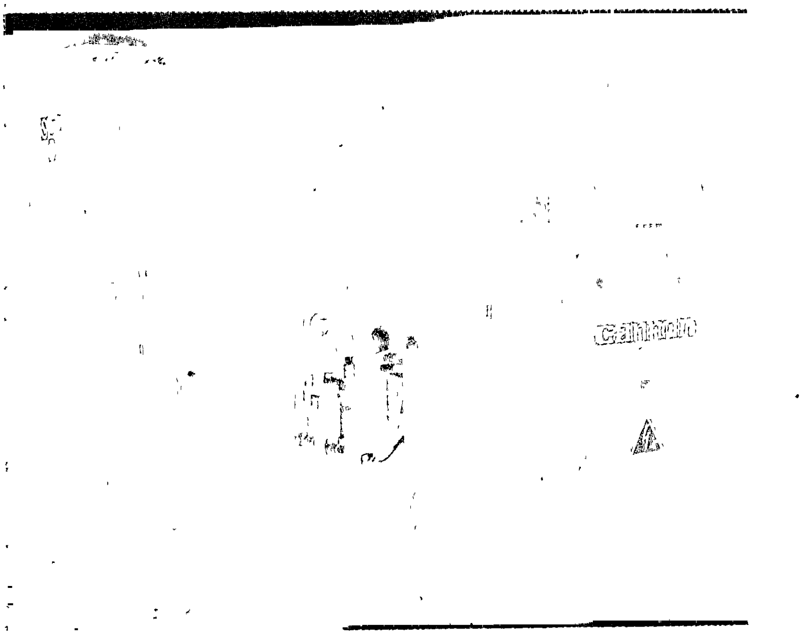


Figure 4. Multi-EasyFroth – dedicated pre-blending unit for LBBAs and pentanes

in a split version). It can be mounted in two separate rooms. The metering unit is linked with the part of premix which is in contact with cyclopentane, and both are in the ventilated box. The pure polyol metering section and the control panels are mounted outside it.

- *Pentamodule.* Pentamodule is a complete kit dedicated to the polyol side of an existing foaming machine, with a tank fitted with a stirrer, which is operated by magnetic coupling to avoid leakages from the stirrer's shaft, and the high pressure metering section for the polyol.
- *A-System Penta.* A-System Penta is a complete high-pressure metering machine containing an integrated polyol/cyclopentane blending unit under the same section (Figure 5).

In general, most of our customers have preferred a configuration with the largest possible ventilated box containing all the potentially dangerous components – formulated polyol tank and high pressure metering unit. Specific construction details have been applied to reduce any risk arising out of accumulation of cyclopentane vapours. The whole equipment is mounted on a walkable grid, and suction ducts are mounted on it.

- *Injection area.* For injection and polymerization area, two examples describe the current trend of this market – a retrofitting solution for an existing plant and a totally new one.

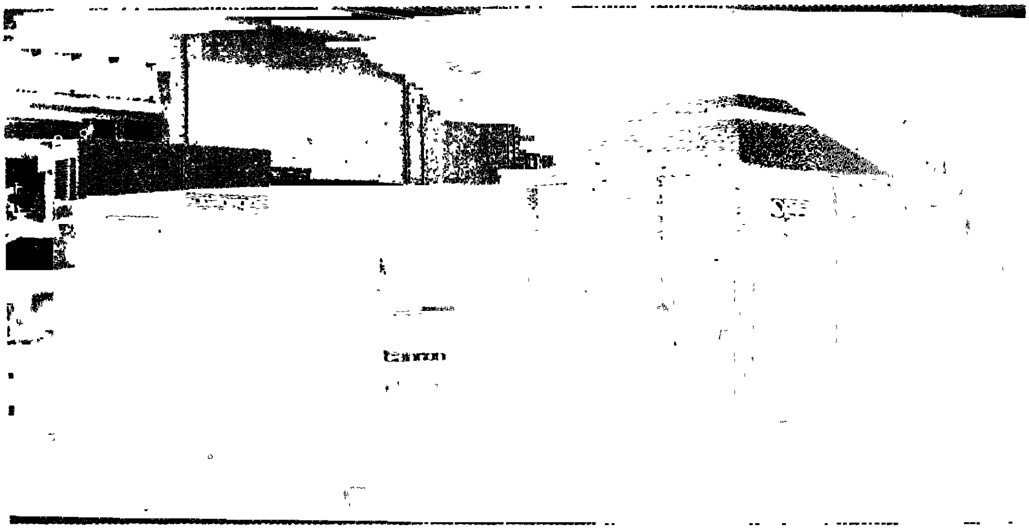


Figure 5. A-System Penta Cannon unit for producing cyclopentane-blown foams

Retrofitting an existing plant

Retrofitting an existing foaming plant represents a complex engineering task as it involves more limitations than supplying a new one. Several existing technical features must be respected. A detailed technical survey is necessary to make a correct price estimate, and the installation should not interfere too much with the production (week-ends and holidays are ideal for this kind of jobs).

The final cost is lower than buying a new plant, but expected savings can be wasted with a wrong approach. The supplier must ensure competent and numerically sufficient personnel for all phases of the job – estimate, engineering, manufacturing parts, installation, and start-up.

Good communications are vital, since a lot of cooperation with the personnel-in-charge of the existing plant is foreseen.

As an example of retrofitting, the following solution shows the case of a multinational company manufacturing refrigerators on two foaming lines of six fixtures each.

In this scheme, a new mezzanine has been added in the middle of the plant, to hold a box, containing the metering units, and a part of the ventilation equipment. The existing foaming fixtures have been enclosed in a ventilated box, with suction points positioned on the upper and lower sides of each fixture, and a positive air displacement device mounted on the roof of the box.

New plant

Designed to guarantee maximum flexibility and capacity in a very tight layout, this plant has been commissioned this year (1996) to the largest refrigerator manufacturer in Italy. Six rotoplug foaming fixtures, each provided with a rotating plug-holder for a zero-time-plug-change, are mounted in two facing rows of the jigs. Space has been provided for a future addition of four foaming fixtures.

The empty cabinets are unloaded from a suspended transfer line and pre-heated in a large oven until they reach a temperature of 50 °C. They leave the oven on the right or the left side through two gates closed by sliding doors, and are loaded on two-place carts that bring them in front of the jig that will unload a foamed cabinet first.

The foaming fixtures are placed in a closed box (classified area, with electric equipment of IP44 execution) fitted with gas sensors and adequate ventilation. Between them, in a service corridor, the mixing heads and their flexible piping can be easily serviced and adjusted. As soon as the jig opens, the door on the box's wall slides up and the foamed cabinet is ejected onto the empty place of the two-place cart and moves one step forward. The empty cabinet leaves the cart and enters the jig. The sliding door immediately closes and the jig's walls clamp the cabinet and lift it towards the plug. The foaming cycle takes place and the polymerization starts.

During the filling phase; the cyclopentane vapour – emitted in a predictable quantity from the venting holes of the cabinet – is captured by the suction system around the jig and sent to the exhaust duct.

All the metering equipment is installed on a mezzanine above the pre-heating oven, enclosed in ventilated box provided with the safeties described earlier.

The premixing devices and the cyclopentane storage are installed in separate safe rooms, where all electric components are of E-Ex execution (i.e. intrinsic safety zone). It is interesting to notice that, being a large installation, the polyol blending function has been specifically engineered so that there is a room fully dedicated to the mixing of polyol and cyclopentane. In a contiguous room, separated by a fireproof wall, all the motors and electric control panels are installed. Safety is improved, maintenance operation on the electric parts can be run without interrupting the blending cycles, and cost has been contained using less expensive electric components.

Technical considerations: mould conditioning

The use of cyclopentane has quickly convinced the producers to switch from electric heating to water conditioning. There are advantages: electric resistances are removed from a potentially explosive area, and water can be used as a coolant should the thermal equilibrium of the mould be influenced by the higher exotherm of partially water-blown formulations. There are disadvantages: fitting water pipes on a foaming fixture is more complex than wiring heating elements. Door plants based on Paternoster or carousel system are more difficult to be water conditioned. Fortunately, there are solutions: Cannon's patented DRUM units are preferred in this case, because a central rotating water collector easily feeds all the moulds mounted on the sides of the rotating machine.

Nitrogen purge of cabinets before injection is still a debated issue. Producers of large cabinets use it because the amount of vapour is larger and potentially more dangerous. Producers of small cabinets like to have the option easily obtainable on Cannon's patented L-shaped mixing heads, but not always use it.

Sandwich panel production

Use of pentane-blown foams for sandwich panel's insulation requires particular attention specially because of the wide size of the production plants: polymerization presses are often as large as 15 × 2 m, and proper ventilation and gas detection of the whole area is a major engineering task.

Cannon has just supplied to Maersk Container Industry in Denmark a large turn-key foaming plant for the production of 'reefers', the 40 feet-long insulated containers used for delivery of perishable goods. Pentane-blown formulations will be usable in this plant, whenever the client will decide to do so. The plant is conceived for the direct injection of polyurethane foam into the two long side-walls and in the roof of the box, while the floor is made by gluing thick slabs of extruded expanded polystyrene (XPS) to the metal facings of the panel.

Technical concept

The whole supply could be described as a sandwich-panel plant, even if its complex configuration goes beyond this description: more than 35 000 different 'parts' per year have to be made, moved, and assembled in the most rational way. The production plant includes:

- three Manni presses for foaming sandwich panels 12.5 × 2.5 m large, with a special open-pouring method found to distribute the foam in the most even way on the whole surface of the panel;
- two Cannon 'A-System 300' dosing units with 6 FPL 24 mixing heads for the open pour distribution of the foam;
- one Cannon Tecnos press for the floor-panel in glued XPS boards, with robot for automatic positioning of polystyrene on the metal sheets;
- one robot for spraying the polyurethane-based adhesive, supplied by Akzo Nobel;
- one panel-storage warehouse, where finished panels are kept until the assembly line needs them; and
- one computerized factory supervision system by Automata, the Cannon Group's electronics division. A token-ring Local Area Network connects 11 knots, 3 being Automata's PC Workstations and 8 Industrial PLCs, and provides the production manager with data related to each single function of the plant.

Conclusions

The use of cyclopentane as blowing agent for polyurethane foams in refrigerator and freezer manufacture is growing. Technical constraints due to its explosive nature have been tackled and are being optimized. The successful experiences of the past two years speak positively for the near future.

Energy-saving legislations are pushing for more efficient refrigerators, and alternative solutions are available today. Cost and manufacture details are still very open points. For the time being, manufacturers can look at cyclopentane as a viable replacement to CFCs, and have their industrial plants on it for the coming 10 years.

For longer... weather forecast, keep in touch: our crystal-ball is always turned on!

Cyclopentane foaming on an industrial scale: technical solutions for new installations

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Foaming technique for the manufacture of refrigerators

Various technological possibilities have been developed in the manufacturing of refrigerators for the foaming of housings and doors (Figure 1).

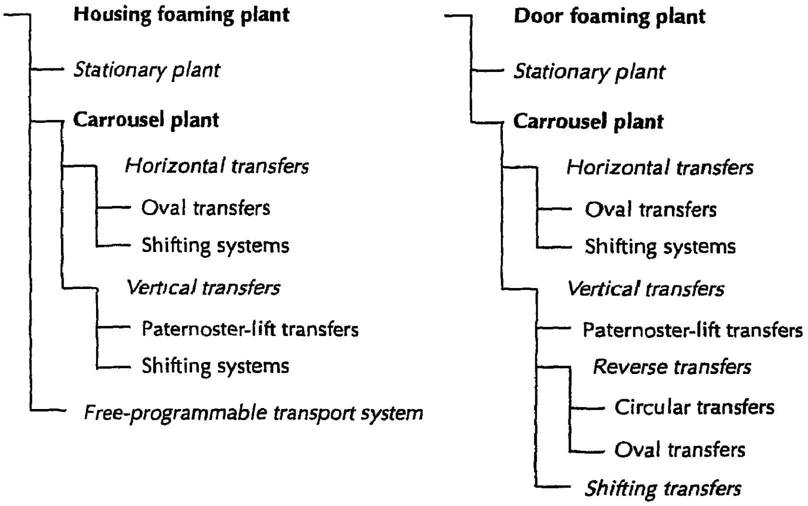


Figure 1. Outline of a foaming plant for refrigerators

The following objective decision criteria have to be considered for the choice of a possibility:

- the number of pieces to be manufactured per shift or year;
- grade of automatization, i.e. manual or mechanical processes;
- flexibility, i.e. how many different types are manufactured in which unit of time; and
- investment expenses/profitability, i.e. after which period of time, the plant will work with profit.

However, subjective decision criteria, like usual methods of working with an existing plant, will speak for or against a plant possibility. In principle, there is a difference between stationary foaming plants and foaming plants with transfer systems. In general, a plant with transfer system works economically if more than 10 supporting moulds are necessary. The use of pentane-blown foams supports this trend appreciably, as the safety technical expenditure for stationary moulds multiplies by the number of moulds, whereas for transfer systems, this expenditure is only necessary in the pouring area.

Foaming plant for housings

The pouring variants for housings are given below (Figure 2).

- Bell position (rear side on the top)
- Tub position (rear side on the bottom)

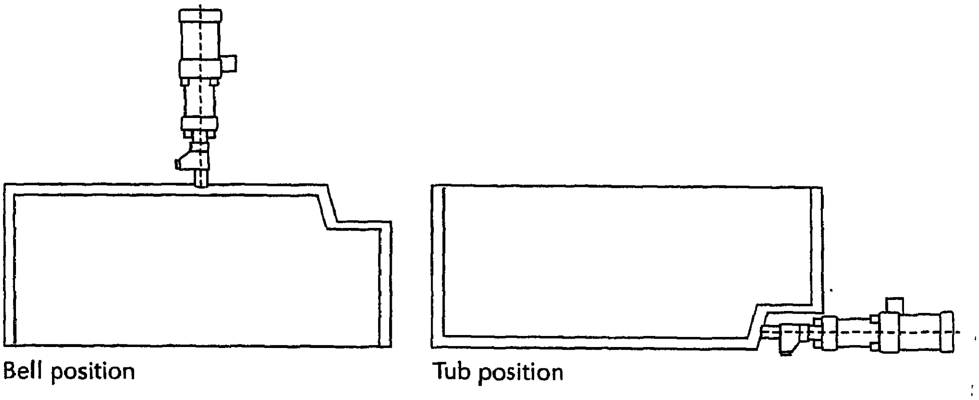


Figure 2. Housing of pouring variants

At the beginning of polyurethane processing in the refrigerator industry, the housing was assembled and foamed in the mould in bell position. However, the bell position has got the disadvantage of poor foam distribution and ventilation due to the quality of requirements regarding the distribution of foam density. The tub position succeeded as optimal foaming position during 1995. The bell position as foaming position is not allowed when using pentane-blown foams, because of safety reasons.

The trend for the foaming moulds changes from single-purpose moulds to changeover and adjustable moulds (Figure 3).

Changeover possibilities exist due to:

- core changes by which several inner contours and wall thicknesses for the same outer dimensions are possible with one supporting mould;
- core changes and side-wall adjustment by which several inner contours, wall thicknesses and refrigerator widths for the same refrigerator height are possible with one supporting mould; and
- core changes, side-wall adjustment, and end-wall adjustment by which several inner contours, wall thicknesses, refrigerator widths and heights are possible.

Core changes and wall adjustments can be realized manually or automatically. A quality supporting mould can adjust refrigerator dimensions – height, width, and depth – by which the customer can eliminate tolerance variations in the prefabrication.

The principal possibilities for temperature regulation of supporting moulds are:

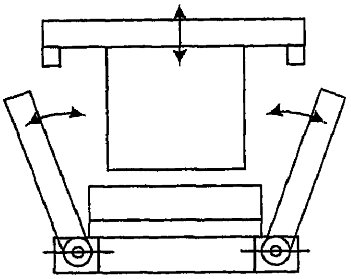
- liquid temperature regulation;
- electric heating panel temperature regulation; and
- circulating air temperature regulation (Figure 4).

Liquid and electric heating panel temperature regulation makes the heating of the supporting walls possible within relatively short time, but are more expensive. The use of electric heating panel-temperature regulation is not allowed when using pentane-blown foams.

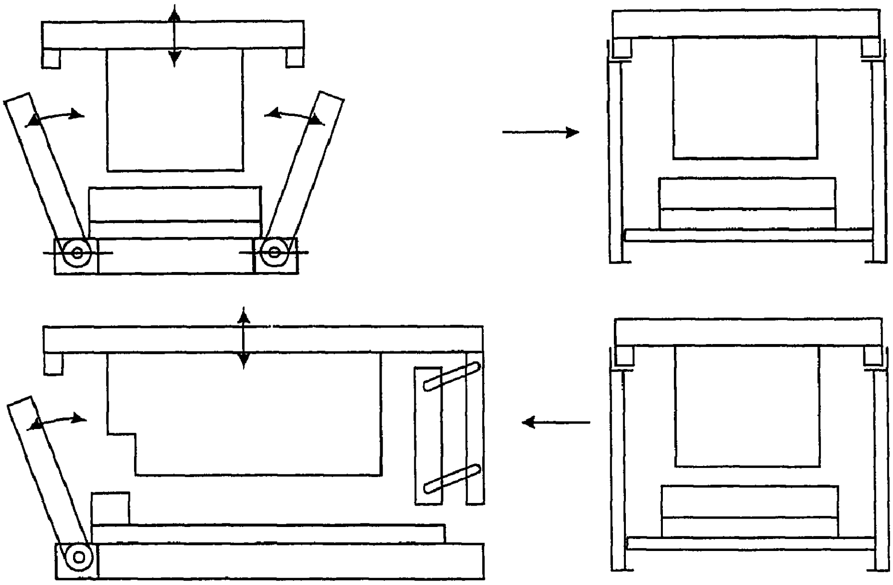
With the possibilities of the automatization technique, handling jobs like laying-in of pre-assembled core housings, pouring, and taking-out of the foamed housing can be carried out in different comfort up to fully automatic.

The laying-in/taking-out is possible as follows:

- manually without auxiliary devices;
- manually on pallet;
- manually on belt conveyor;
- automatically over roller conveyor/belt conveyor; and
- automatically with laying-in/taking-out manipulators.



Single-purpose moulds



Changeover or adjustable moulds

Figure 3. Mould conceptions

The possibilities for the pouring are as follows:

- manual, mixing head on traversing rail and balancer;
- manual, mixing head on traversing carriage;
- automatic, mixing head on driven traversing carriage with positioning device;
- mixing head mounted at mould; and
- mixing head on pouring manipulator.

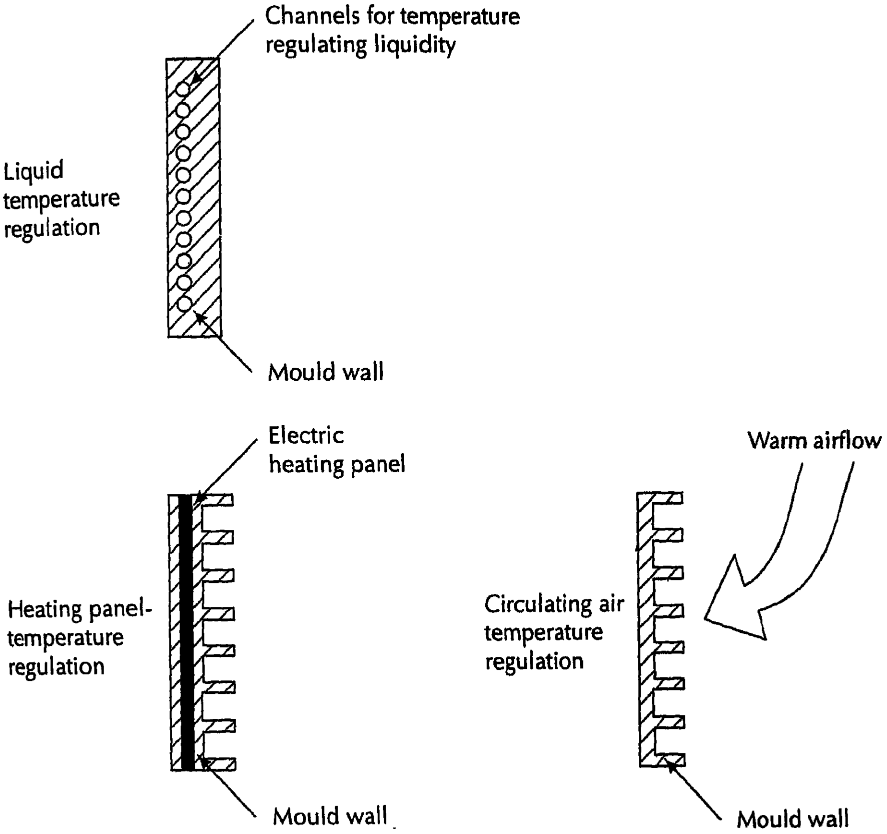

Channels for temperature regulating liquidity
Liquid temperature regulation
Mould wall
Electric heating panel
Heating panel-temperature regulation
Mould wall
Warm airflow
Circulating air temperature regulation
Mould wall

Figure 4. Principles of temperature regulation

The typical changes of a stationary foaming plant for housings are as follows:

- central feeding line from the pre-assembly;
- distribution transfer device to the stationary moulds;
- intermediate storage for empty housings;
- pre-heating oven for each supporting mould;
- the stationary supporting moulds; and
- central re-transfer line to final assembly.

The wet parts – metering machine and premixing station – are normally placed on platforms above the supporting mould in order to have the shortest possible pipe distances.

Transfer systems are with central feeding line from the pre-assembly and preheating tunnel, laying-in manipulator, pouring manipulator, transfer line in curing tunnel temperature regulated with circulating air, taking-out manipulator, automatic mixing head cleaning station, central heating station, and mould changeover station outside the transfer system. These systems have got the advantage of a compact design and high flexibility.

Foaming plant for doors

When foaming doors, main differences are between pouring into the closed mould and open mould. A foam density distribution of higher quality is possible by pouring into the open mould. The decision, whether it is poured into a closed or open mould, essentially depends on the possibility of quick mounting of the inliner including door packing with the outer sheet metal housing. Also, the order of foaming and assembling can be:

I
- laying-in of outer sheet metal housing,
- foaming, and
- laying-on of inliner;

or

II
- laying-on of inliner,
- foaming, and
- laying-in of outer sheet metal housing.

The order decisively depends on the possibility of automatic assembly. In Case I, better ventilation of the interior space is given. The doors are often foamed with release paper or release film as compromise solution and inliners are mounted on a separate working step.

All handling works in the door foaming plants can be carried out automatically with:

- laying-in of outer sheet metal housing;
- foaming;
- laying-on of the inliner;
- dosing and locking of the mould;
- unlocking and opening of the mould; and
- taking-out of the foamed door.

The easiest possibility is the manual operation of the supporting mould and the mixing head. Transfer systems are clearly in the trend for door foaming.

Complex systems will increasingly be successful with:

- laying-in manipulators;

- pouring manipulators;
- automatic opening and closing stations;
- cleaning stations;
- transfer systems in several levels;
- curing line heated with circulating air; and
- automatic line for sluicing in and out of the supporting mould changeover units with changeover working places outside the transfer system.

The controls for housing and door-foaming plants are memory-programmable, which can be switched for larger plants as a network through personal computers. Mould recognition systems are a necessary prerequisite for flexible automatic plants. Process and production data are recorded, stored, and visualized on screen.

Processing of pentane-blown foams: pentane safety technique

The phasing out of the ozone-depleting foam-blowing gases is in full swing. In the Montreal Protocol, the world community has irrevocably declared its commitment for it. The time schedules for the phase-out are binding. In Germany, all ozone-depleting blowing gases are prohibited beginning from end of 1995. Worldwide, it is agreed upon a ban up to the year 2000.

What is the alternative? In many cases, people orientate on the so-called 'soft CFCs'. For example, substances like R141b have got considerable residual ozone depleting potential (ODP) and global warming potential (GWP); R134a has considerable GWP (Table 1). Therefore, an uncompromising alternative is cyclopentane. Cyclopentane is a natural gas without ODP and with a negligible influence on global warming. Cyclopentane is the alternative for the future with virtually the same

Table 1. ODP and GWP values of various blowing agents

Blowing agent	ODP	GWP
CFC11	1	1
HCFC22 (hydrochlorofluorocarbon)	0.05	0.35
HFC134a (hydrofluorocarbon)	0	0.26
HCFC141b	0.09	0.09
HCFC142b	0.06	0.36
Pentane	0	0.001
CO_2	0	0.0003
Air	0	0

characteristics regarding thermal conductivity and diffusion as are reached with CFC11.

Besides plants for pipe insulations and sandwich elements for wall and roof, the German refrigerator manufacturers have also fully converted to cyclopentane-blown foams or have newly invested in plant technique for cyclopentane-blown foams. With regard to processability, heat insulation, and form stability, cyclopentane-blown foams are comparable with the known CFC11 blown foams.

Also, with the pentane processing technique developed by Plasttecnnik Greiz GmbH (PTG), a number of foaming plants could have been converted or newly manufactured in the past two years. The first CFC-free refrigerator was manufactured with PTG plant technique. Cyclopentane is a saturated hydrocarbon (HC) (chemical C_5H_{12}) in liquid state. Special safety precautions are necessary for the processing of pentane. For this, PTG has developed a safety concept from tank up to finished moulded part which has been examined and certified by the German Technical Examination Association (TUV) in accordance with the legal basis listed below:

- Ordinance on electric plants in rooms exposed to danger of explosion - Elex V
- Ordinance on pressure tanks - DruckbehV
- Ordinance on plants for storage, filling and conveying of inflammable liquids by land - VbF
- Regulations on prevention of accidents and guidelines according to VBG
- EN/DIN VDE Regulations
- Explosion-proofing guide of practices - BG-Chemie
- Water resources act - WHG

The safety concept includes a number of primary and secondary measures, which enable maximum safety in their unit and reciprocal interaction, and eliminate human failure to a great extent.

Primary safety measures

Primary safety measures to prevent the development of an explosive pentane air-mixture in all steps of processing from tank up to foaming mould are listed below.

- Special pipings and sealing
  - double seals in case of static connections
  - double seals with monitored liquid seals for dynamically stressed sealings at pumps and valves
- All pentane containing tanks are nitrogen-pressurized
- Exclusive use of components (e.g. drives, magnetic switches, transmitters, sensors, switching elements) with Conformity Certificate of the Physical-Technical

Federal Institution Braunschweig (PTB-Certificate) or Safety-Technical Certificate of the Federal Institution for Material Testing (BAM-Certificate) in the X and safety zones
- Pentane containing tanks with agitator bushing by magnetic coupling, therefore no sealing and no leakage
- Constant ventilation of the polyol–pentane mixture pump by special ventilation pump
- Quantity-controlled nitrogen application in closed foaming moulds with type-certified high-pressure mixing head (patent pending)
- Pentane tank storage, underground or overground with double-walled tanks and pipes according to DIN 6608/2 including safety fittings
- Locking of the pentane containing plant elements on hardware and software side by switching off and locking automatics

Secondary safety measures

Secondary safety measures for additional safety in case of damage or breakdown are given below.

- Housing of all possible leakage points
- Exhaustion of all housed plant components by two-stage ventilation system
  - Baseload during normal operation
  - Live load (5-fold air exchange) in case of inconveniences
  - Special blower in spark-stopping design
- Air-flow monitoring by flow sensors at all exhaustion points
- Pentane sensors in tank area, premixing, metering, discharging with evaluation electronic and gas warning system
  - in case of pentane ratios attaining 20% of the lower explosibility limit (LEL), malfunction message and exhaustion with live load are switched on
  - in case of pentane ratios attaining 40% LEL, the plant electric power is switched off (except for exhaustion as well as pentane and blower sensors) and exhaustion with live load is switched on
- Evaluation units for liquid seals
- Potential equalization at all plant components according to DIN VDE 0100

Premixing technique

The premixing technique is drafted out in such a way that the customer can use all possibilities for raw material feeding on pentane as well as on polyol side. The polyol can be delivered from barrel, from container or tank into the polyol intermediate tank. The same applies for pentane, whereas for refilling from the barrel or container, these are moved into the housed area of the premixing station. With that, the plant personnel have got an absolute safety when charging the premixing station by hand. Especially client-oriented is the moving slide integrated in the premixing station which enables an easy moving in and out of barrel or container. The filling of pentane into the pentane intermediate tank is carried out by pump (from barrel) or nitrogen pressurization (from container).

The premixing station has got a polyol intermediate tank (filling volume 150 litre) with a control level for maximum, minimum, and shortage. With this, an automatic refilling from barrel, container or tank is given, and it is ensured in any case that no air comes into the polyol circuit.

Polyol and pentane are conveyed in the recirculation circuit before metering and mixing. This way constant pressure and temperature conditions for the whole metering cycle and constant conveying conditions in the measuring ranges of the mass flow meters (measuring principle Coriolis force) are guaranteed.

The premixing station has got separate metering pumps (action principle gearwheel) for polyol and pentane. The polyol pump is designed as constant feed pump and the pentane pump is equipped with a frequency controlled drive. Recirculation and separate metering pumps are the prerequisites for a high-precise metering. The premixing station has got a mass flow meter for each, the polyol and pentane circuits. By volume-related metering, the influence of pressure, temperature, and viscosity is excluded. For mixing of polyol and pentane, a special static mixer in two-stage design with post-mixing is used. With it, high-class mixing in quality is realized. A demixing is excluded. The premixing station is manufactured in three sizes.

Machine tank

The machine tank is equipped with an agitator with magnetic coupling. This way, a possible gas leakage at the shaft sealings is avoided. The tank has got a nitrogen blanket. Thus, the pentane cannot form a compound within oxygen inside the tank, and, therefore, no ignitable mixture can form. The tank is connected with a 'pressure tank' on nitrogen side, so that no pentane mixture can escape during filling. Machine tank and pressure tank are equipped with pressure relief valves which again are connected to the existing exhaustion pipe.

The nitrogen pressure is monitored by a pressure sensor regarding minimum pressure. This way, it is secured that nitrogen is always available and an inertization of the tank is guaranteed.

In case the pressure falls below the minimum pressure, the metering machine is switched off and the valves at the inlet and outlet of the tank are closed. The machine tank gets an overfilling safety device (tuning-fork principle). When the overfilling safety device responds, the premixing station and the tank filling will be switched off. No new metering process can be carried out. Only after finding out the reason and quitting, this will be possible. The maximum and the minimum levels for refilling in the machine tank are detected through a continuous working probe (float principle with magnetic transmission). The refilling is carried out in a defined range. When the minimum filling level responds, the metering machine is switched off after the end of the shot. No new metering process can follow. It has to be refilled.

Metering unit

For the metering unit, the reliable high-pressure metering machines of the type series GH-P (P = pentane design) are used. The shaft sealings at the axial piston pump of the metering machine have got double sealings with monitored liquid seals. The hand wheel adjustment on polyol side of the axial piston pump is monitored in the same way. The ventilation of the polyol/pentane-axial piston pumps is carried out by a ventilation pump equipped with a magnetic coupling in the closed line system. The shaft sealing of gape-type fits on polyol-pentane side is also monitored with a liquid seal.

The ball taps in the medium containing pipings have to undergo a special leakage test which is certified by the TUV separately. Pipe connections are principally equipped with double-sealing screwings.

Inertization

An inert gas – as a rule, nitrogen – has to be used in place of air. In the case of CFC11 blown foams, air is used to pressurize tanks or something of that kind; but an explosive mixture is formed in certain concentrations in the process (Table 2).

Table 2. Properties of foaming agents

Foaming agent	Boiling point (°C)	Density at 20 °C (kg/m³)	Thermal conductivity (W/mk)	Explosion limit (% vol)
CFC11	23.8	1476	0.090	—
N-pentane	36.0	626	0.015	1.4–8.1
Isopentane	28.0	619	0.014	1.4–7.6
Cyclopentane	49.0	750	0.011	1.6–8.7

The signalling of gas alarm (at 20% and 40% LEL) and the indication of leakage are to be forwarded to a permanently occupied place during the production rest time. In case of power failure, it has to be ensured that pentane monitoring and further exhaustion remain in function (emergency generator set).

The role of the customer is also important. Listed below are certain safety measures that have to be followed.

- Read the manual for operation, maintenance, and reaction in case of breakdown
- Look out for danger signs and markings
- Install mobile pentane leakage detection device
- Maintain the pentane sensor system by specialists periodically
- Mark emergency exits and lighting
- Keep fire extinguishers handy
- Install lighting protection system for buildings

The safe use of pentane-blown rigid polyurethane foam systems on refrigerator cabinet and door insulation lines

J J Gardner
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Introduction

The use of a highly flammable material (pentane) as a blowing agent in the production of closed cell rigid polyurethane foam presents the converter, from polyurethane components to rigid foam, with production and procedural changes of a magnitude never before encountered in the history of development. Critical areas of polyurethane foam-insulation production lines must be changed to counter the fire and explosion risks associated with the possible emission of flammable liquid or gas. Changes in working procedures, which take into account the hazards arising from the presence of a highly flammable material in the production chain, must be introduced. The objective of this paper is to provide a general guidance as to where changes must be made, and how well-established statutory regulations, covering the safe use of highly flammable materials, provide answers to the potential fire and explosion risks.

Necessary conditions for fire

Given the presence of a flammable component, oxygen, and an energy source, the outbreak of fire is always possible. If the flammable component and oxygen are present in particular ratios and a high enough energy source provided, an explosion will occur.

Safety regulations

The transport, storage, and use of highly flammable materials (in our case pentane) are controlled by mandatory regulations. These safety regulations guide the engineer and flammable material end-user to the required level of engineering safety.

What we must first understand is that flammable materials are not alike when it comes to ease of ignition, seepage, and energy release on ignition. Various authorities throughout the world have drawn up tables, grouping flammable materials on a 'risk' basis and indicating the standard of engineering safety required.

Table 1 and Table 2 (E.E.C. CENELEC EN50014) (I.E.C. 79-1 B.S.4683) indicate where pentanes typically fit into the group of flammable materials. The group designation II A is important in identifying the correct level of engineering specification required to ensure safe operation.

Table 1. Position of pentane in grouping of flammable materials

Products	
Methane (fire damp)	Group I
Acetone	Group II A
Industrial methane	
Butyl alcohol	
Ethyl alcohol	
Ethyl acetate	
Methanol	
Butane	
Propane	
Hexane	
Ammonia	
Blast furnace gas	
Carbon monoxide	
Pentane	
Heptane	
Iso-octane	
Decane	
Benzene	

Table 2. Position of pentane in grouping of flammable materials

Products	
Methane (fire damp)	Group I
Acetone	Group II A
Industrial methane	
Ethyl acetate	
Methanol	
Butane	
Propane	
Hexane	
Ammonia	
Carbon monoxide	
Pentane	
Heptane	
Iso-octane	
Decane	
Benzene	

Area classification definitions

The statutory regulations provide area classification definitions for zones, areas in which explosive gas–air mixtures will or may occur (Table 3). Most of the area classifications provided by other authorities use similar definitions.

For rigid polyurethane foam producers, it is realistic to engineer the critical parts of the production chain to meet the Zone 2 definitions. Note that the area classification definitions refer to 'explosive' gas–air mixtures. So far, two important engineering safety identification points have been identified. First, pentanes are included in Group II A of flammable materials, and areas of operation, where explosive emissions could occur, will be engineered to meet Zone 2 requirements.

We now have to look more closely at the pentane we are going to use. From the physical properties of cyclopentane, we can identify the material characteristics that present particular risks in our production situation and determine the standard of safety engineering to be used (Table 4). Three properties are critical: (1) auto-ignition temperature (related to temperature class); (2) vapour density (relative to air); and (3) explosive limits (when mixed with air).

Table 3. Area classification definitions

Zone	Definition
Zone 0	A zone in which an explosive gas–air mixture is continuously present or present for long periods
Zone 1	A zone in which an explosive gas–air mixture is likely to occur in normal operation
Zone 2	*A zone in which an explosive gas–air mixture is not likely to occur and if it occurs it will only exist for a short time*
Non-hazardous	An area in which an explosive gas–air mixture is not expected to be present in quantities such as to require special precautions for the construction and use of electrical apparatus

Table 4. Physical properties of cyclopentane

Physical properties	Values	Critical properties
Boiling point (°C)	49	
Melting point (°C)	–94	
Flash point (°C)	–38	
Auto-ignition (°C)	380	Temperature class, T2 (for n-pentane T3)
Relative density (water = 1)	0.8	
Relative vapour density (air = 1)	2.4	Heavy vapour
Vapour pressure (in mbar at 20 °C)	335	
Solubility in water	None	
Explosive limits (vol. % in air)	1.5–8.7	Low concentration
Relative molecular mass	70.1	
Typical occupational exposure limits [(a) in ppm (b) in mg/m³]	600 (a) 1800 (b)	

For our production chain, we can now identify a third engineering safety requirement, when using cyclopentane as a blowing agent, i.e. the maximum equipment working temperature, T2 (300 °C). If n-pentane is to be used, auto-ignition temperature (285 °C), and then temperature class T3 (200 °C) equipment limits will be applicable. More information on temperature class is provided in Table 5.

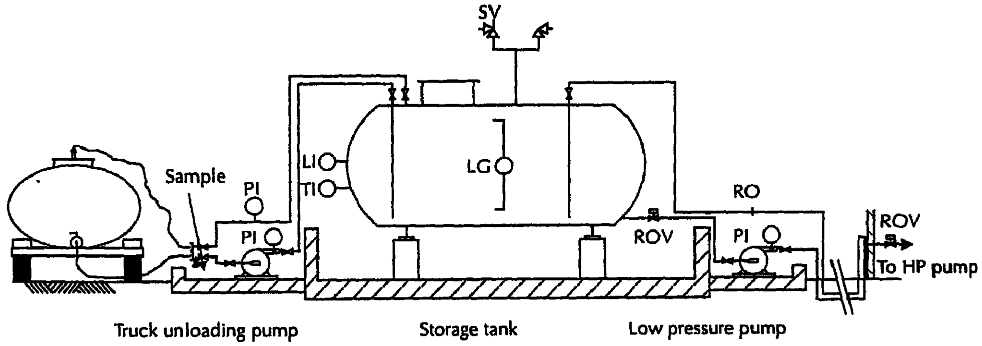
Table 5. Information on temperature class

Temperature class	Maximum surface temperature (°C)
T1	450
T2	300
T3	200
T4	135
T5	100
T6	85

Pentane gas emissions will be 2.4 times heavier than air and will tend to drop to floor level, rather than rise. Gas–air mixtures within the indicated explosive limits (vol. % in air) of 1.5–8.7 must be avoided, usually by dilution with excess air.

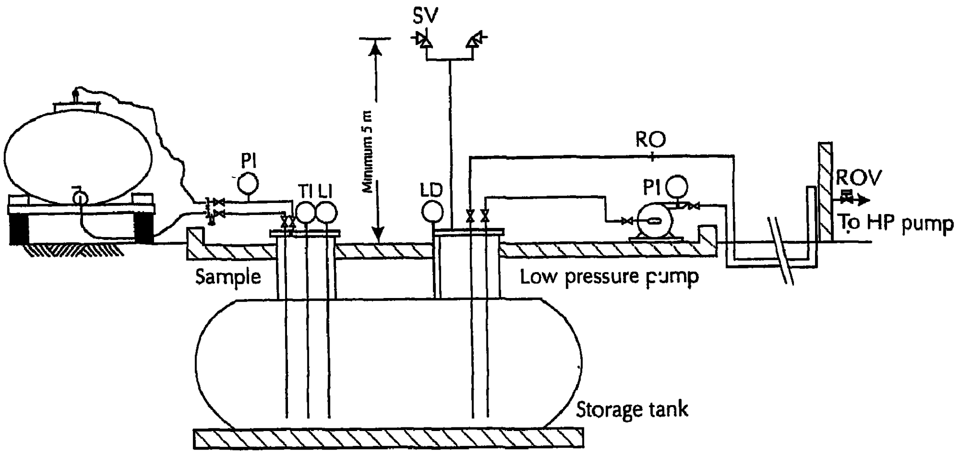
Cyclopentane transportation and storage

As previously stated, the transportation and storage of highly flammable materials are covered by statutory regulations. There will be more local variations in the regulations and requirements for this stage of the production chain than elsewhere. However, regulations such as (1) road tanker and bulk storage tank specification; (2) road tanker entrance/exit to/from site; (3) disposition of the road tanker, the storage system connection point; and (4) the bulk storage tank – above/below ground are included (Figures 1 and 2).



Note: LG – Level gauge; LI –Level indicator; PI – Pressure indicator; RO – Restriction orifice; ROV – Remote operated valve; SV – Safety valve; TI – Temperature indicator

Figure 1. Typical aboveground pentane storage



Note: LD – Level detector; LI – Level indicator; PI – Pressure indicator; RO – Restriction orifice; ROV – Remote operated valve; SV – Safety valve; TI – Temperature indicator

Figure 2. Typical underground pentane storage

All the activities and equipment shown must comply with Zone 2, Group II A, and T2 or T3 specifications when cyclopentane or n-pentane is being transported, transferred, and stored. Figure 3 illustrates how small-scale pentane supply systems can be engineered to comply with Zone 2, Group II A, T2 or T3 requirements.

Working practices

Working practices will have to be changed, new procedures introduced, etc. in order to counter random potential ignition sources, particularly, an electrostatic discharge. In relatively low humidity conditions, line operators and general working conditions can result in significant electrostatic discharges occurring. In the presence of an explosive gas–air mixture, such discharges can result in fire coupled with explosion.

Listed below are some of the precautions to be taken.

- Wear shoes with conductive soles
- Wear cotton overalls
- Maintain contact with clean steel or concrete floors around the production line
- Use metal tools and containers which can be earthed

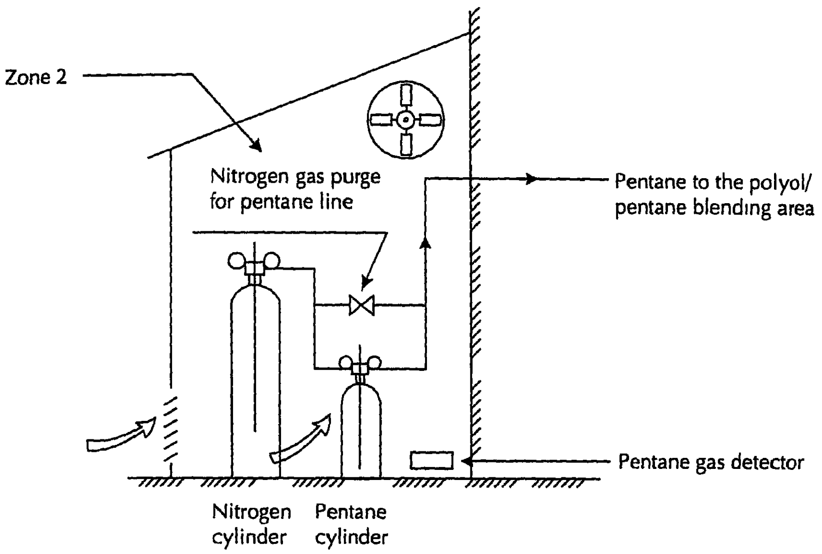

Zone 2
Nitrogen gas purge for pentane line
Pentane to the polyol/ pentane blending area
Pentane gas detector
Nitrogen cylinder
Pentane cylinder

Figure 3. Pentane supply system located outside the main factory area

Pentane/polyol stream

Having discussed transport and storage of pentanes, we can now look at the blending, blend storage, and metering of pentane/polyol components (Figure 4) and discuss how the identified regulations/engineering standards could be applied. Zone 2, Group II A, T2 or T3 must be applied to the following stages:

- polyol and pentane component blending (Figure 5);
- the storage of a polyol/pentane blend (Figures 6 and 7); and
- the metering pump for the polyol/pentane blend (Figures 6 and 8).

Zone 2, Group II A, T2 or T3 requirements

Zone 2, Group II A, T2 or T3 requirements can be applied to the activities of polyol/ pentane blending, polyol/pentane blend storage, and polyol/pentane blend metering. The main features of engineering, in addition to the Zone 2, Group II A, T2 or T3 compliance, are the enclosure of critical equipment, constant extraction during operation, pentane gas detection, and earthing (Figure 9).

Pentane gas detectors should be calibrated to detect pentane emissions well below the lower explosive limit (LEL). It is suggested that a warning should be given

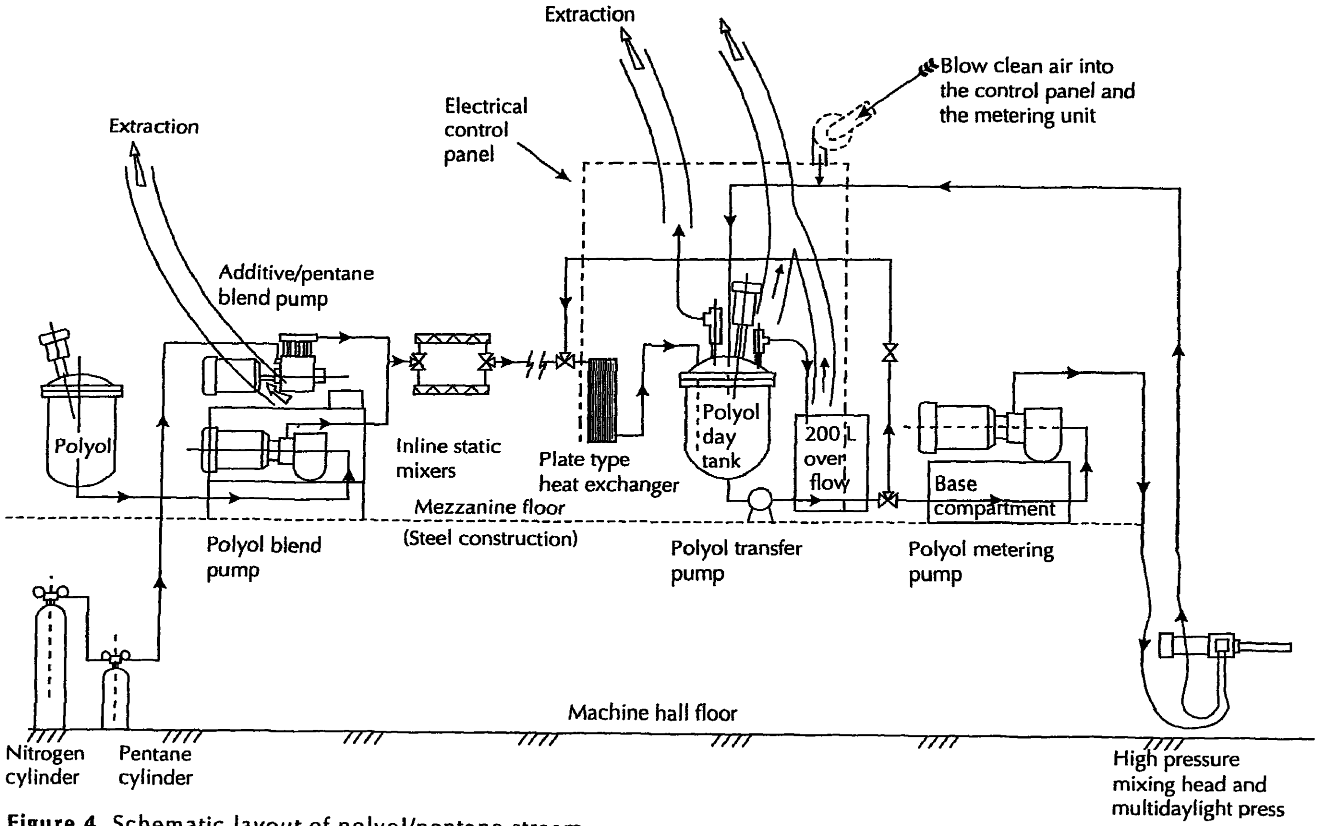


Figure 4. Schematic layout of polyol/pentane stream

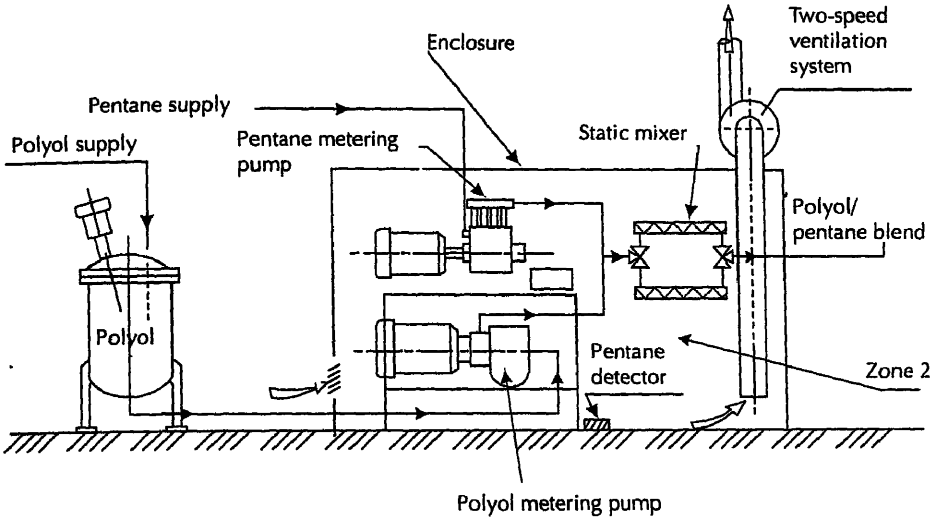


Figure 5. Typical polyol/pentane blending system

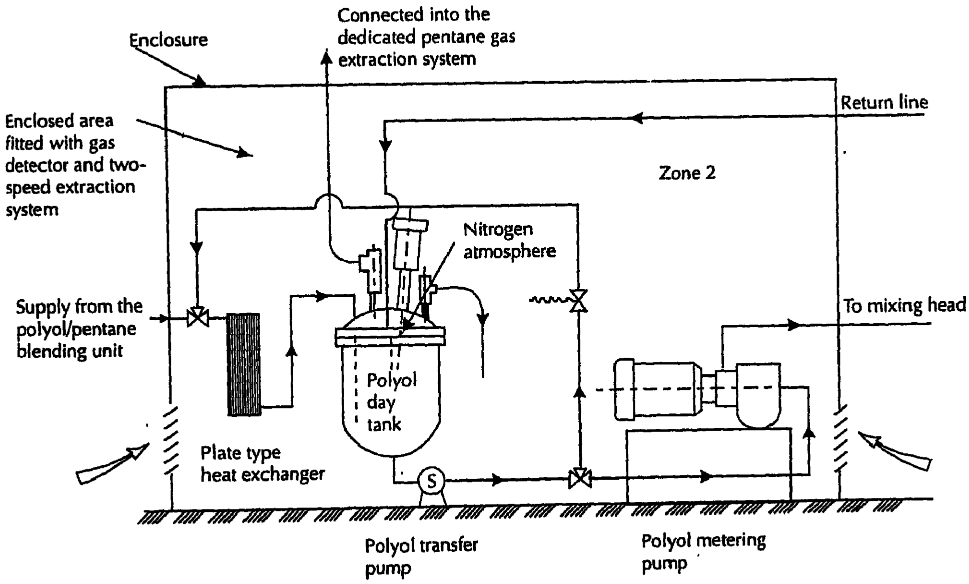

Enclosure
Connected into the dedicated pentane gas extraction system
Return line
Enclosed area fitted with gas detector and two-speed extraction system
Zone 2
Nitrogen atmosphere
Supply from the polyol/pentane blending unit
To mixing head
Polyol day tank
S
Plate type heat exchanger
Polyol transfer pump
Polyol metering pump

Figure 6. Polyol/pentane machine tank and metering unit

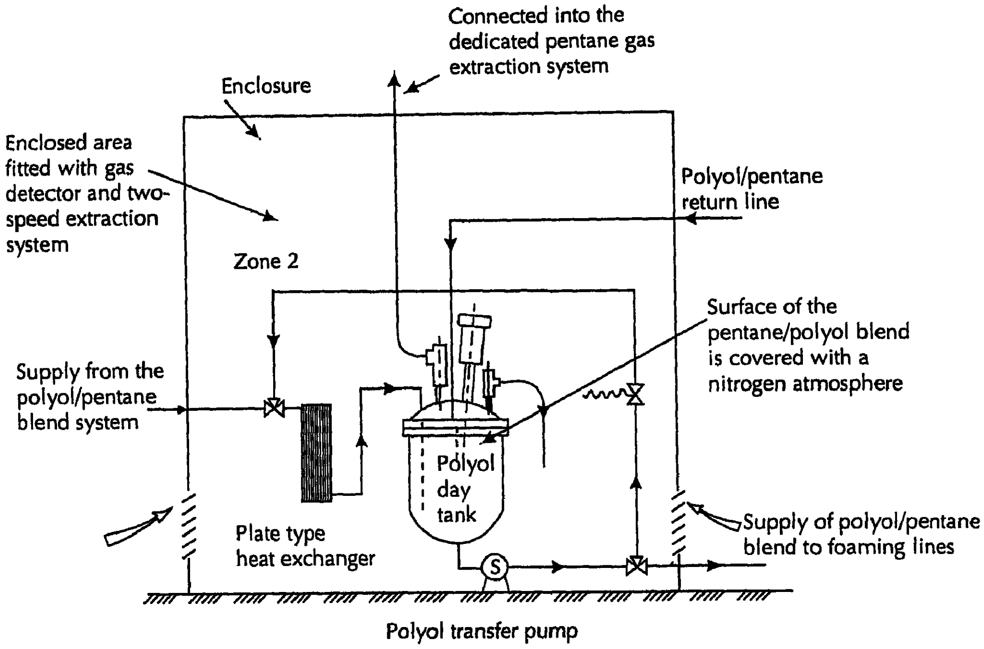

Connected into the dedicated pentane gas extraction system
Enclosure
Enclosed area fitted with gas detector and two-speed extraction system
Zone 2
Polyol/pentane return line
Surface of the pentane/polyol blend is covered with a nitrogen atmosphere
Supply from the polyol/pentane blend system
Polyol day tank
Plate type heat exchanger
S
Supply of polyol/pentane blend to foaming lines
Polyol transfer pump

Figure 7. Polyol/pentane day tank

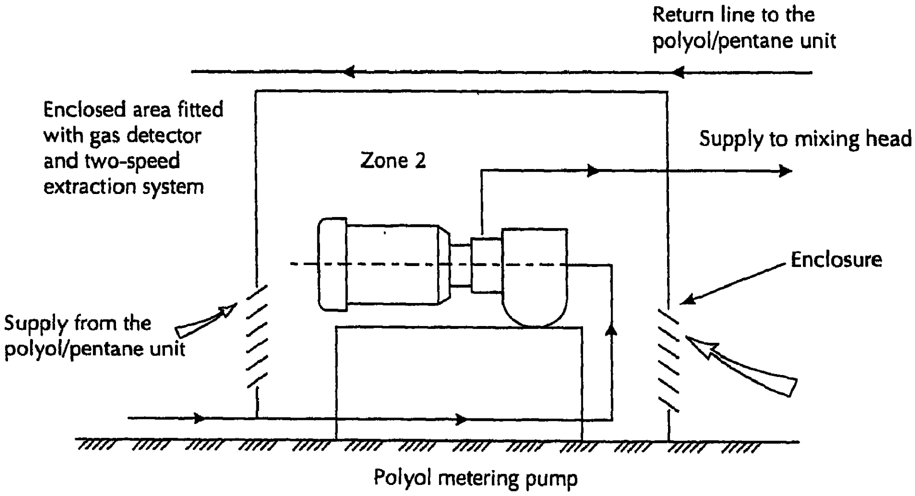

Return line to the polyol/pentane unit
Enclosed area fitted with gas detector and two-speed extraction system
Zone 2
Supply to mixing head
Enclosure
Supply from the polyol/pentane unit
Polyol metering pump

Figure 8. Polyol/pentane metering pump

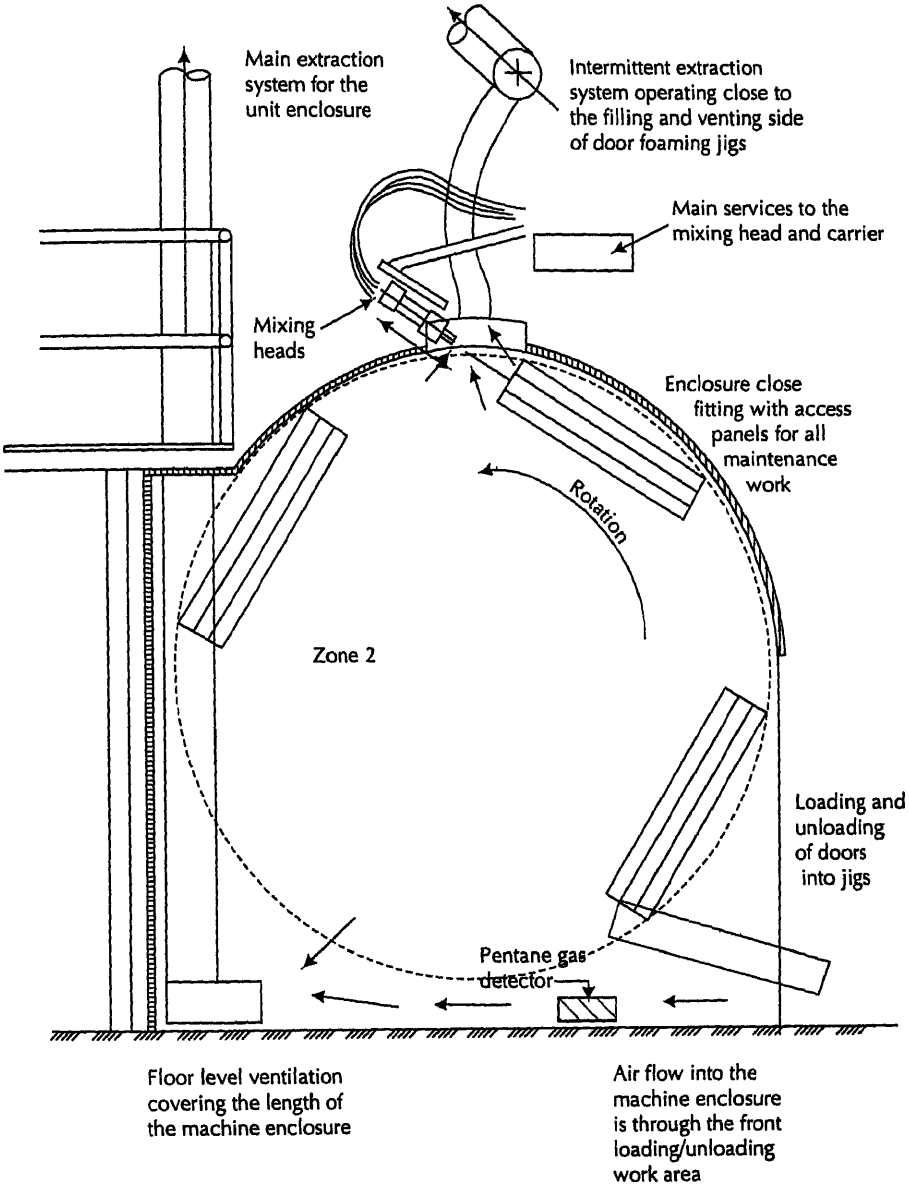

Main extraction system for the unit enclosure
Intermittent extraction system operating close to the filling and venting side of door foaming jigs
Main services to the mixing head and carrier
Mixing heads
Enclosure close fitting with access panels for all maintenance work
Rotation
Zone 2
Loading and unloading of doors into jigs
Pentane gas detector
Floor level ventilation covering the length of the machine enclosure
Air flow into the machine enclosure is through the front loading/unloading work area

Figure 9. Main features of the extraction system

at 10% of the LEL and the volume of air extraction system should be increased. If the pentane emission continues and increases to say 25% or 30% of the LEL, the pentane supply must be shut down to all parts of the line and emergency procedures followed.

Protection of electrical control cabinet

To reduce the cost of converting a rigid polyurethane foam production line for the safe use of a pentane-blown system, some pieces of standard electrical equipment can be removed to a specific minimum distance from a high risk area and put under a slight positive air pressure (Figure 10). This would prevent any flammable gas emissions from entering the equipment in the event of an accident.

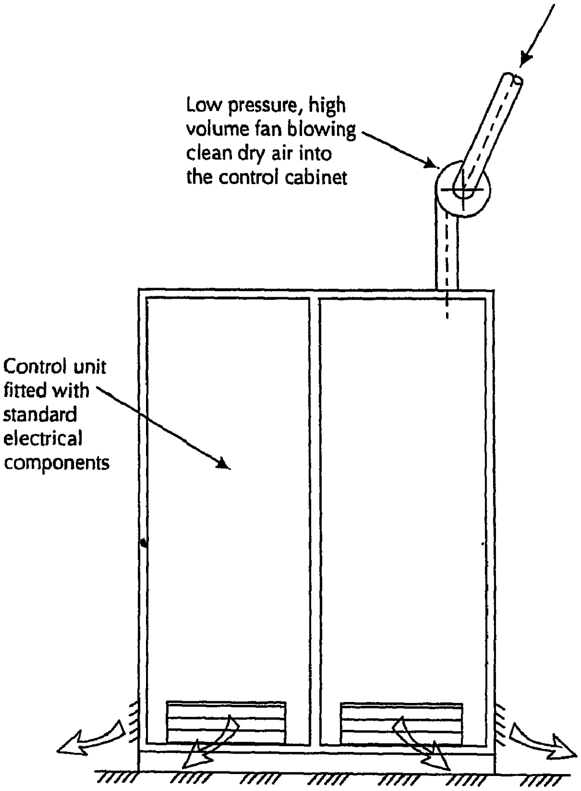

Low pressure, high volume fan blowing clean dry air into the control cabinet
Control unit fitted with standard electrical components

Figure 10. Increased air pressure system used to protect electrical control cabinet

Protection of critical areas of the polyurethane component processing line

It is achieved by (1) correct electrical specification; (2) ventilation (under pressure, over pressure); (3) enclosure of equipment process stages/activities; (4) earthing of each stage/activity on a common system; and (5) monitoring for pentane gas emissions.

It is important that work procedures should be reviewed and, where required, replaced or upgraded to take into account the risks associated with the possible presence of a flammable or explosive gas emission.

It should be remembered that containers and equipment, which have been in contact with pentane or polyol/pentane blends, can also present a fire or explosion risk when empty or transferred to other activities, if flushing procedures are not followed. Correct and comprehensive procedures should be written for the decontamination of equipment and containers.

Explosion limits

Pentane gas emissions occur during the polyurethane component dispensing and expansion stages in either a free rise or refrigerator cabinet insulation operation. High concentrations of pentane gas can be detected close to the surface of a free-rise foam or at the breathing holes exhausting the free air from inside a closed volume being insulated with pentane-blown rigid polyurethane foam. Measurements and calculations suggest that less than five per cent of the pentane injected into a container is lost during the polyurethane foam expansion process. Where the flow characteristics within a refrigerator cabinet or door are good/easy, the loss of pentane gas can be as low as 2.5%–3.0% by weight (Figure 11).

Based upon the measured/calculated pentane losses, it is possible to estimate how much flammable gas must be collected during the various insulation processes. Pentane emission from a closed volume, which is being filled with a rigid polyurethane foam, will vary from zero at the start of the foam expansion to well over the LEL at the end of the foam rise (Figure 12).

We can now estimate how much pentane gas will be emitted into the workplace and when it will be emitted during the insulation of a refrigerator cabinet or door.

Dispensing and rise stages of the polyurethane foaming

Once again, Zone 2, Group II A, and T2 or T3 standards must be adhered to in the dispensing and rise stages of the polyurethane foam insulation of refrigerator cabinets and doors. The risk of emission of flammable gases exists from the start of

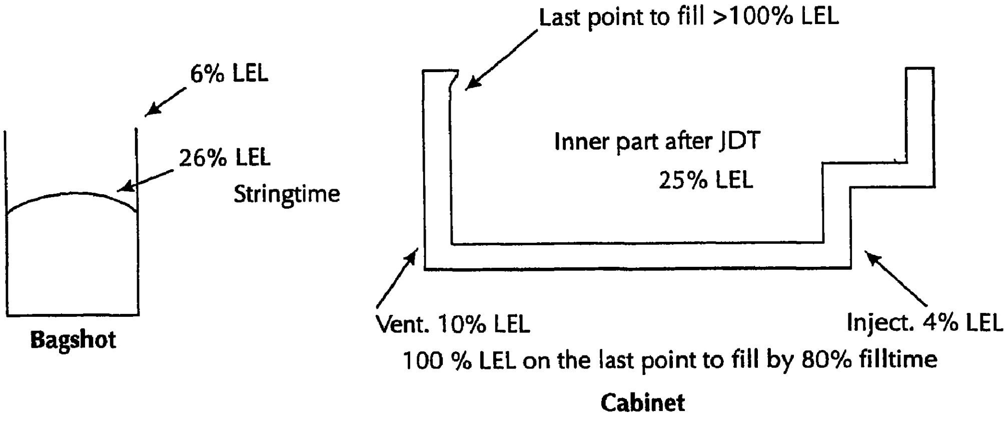


Figure 11. Pentane emission from free-rise polyurethane foams

injection to the end of the foam rise. During this +60 second period, the foaming jigs and the adjacent production line area must be treated as Zone 2. Enclosure, extraction, earthing, and pentane gas detection must be applied to ensure safety (Figure 13).

It is more important than ever to remember at this stage of production that pentane gas emissions, being 2.4 times heavier than air, will tend to pool or collect below the jigs and flow into the lowest parts of the factory. Service ducts and access

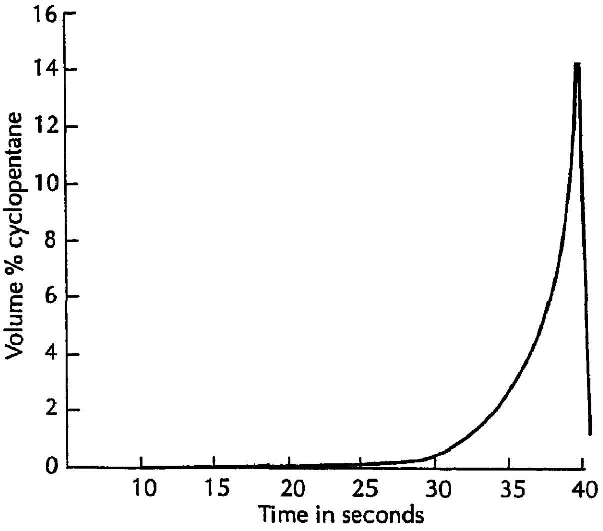


Figure 12. Pentane vapour emissions from a closed panel

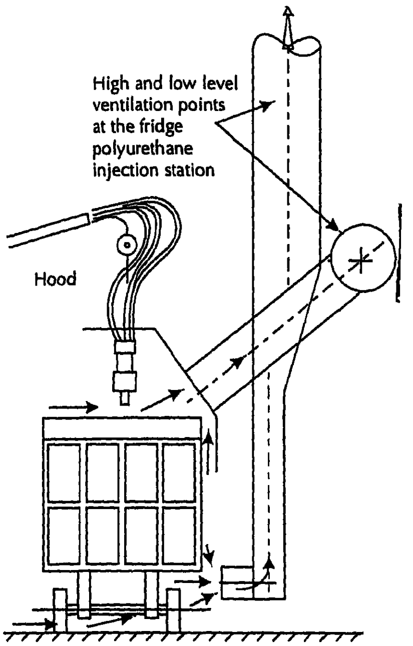

High and low level ventilation points at the fridge polyurethane injection station
Hood

Figure 13a. Refrigerator jig at the polyurethane injection station

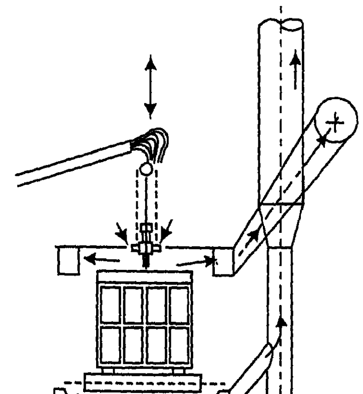


Figure 13b. Refrigerator jig at the polyurethane injection station (as shown, the jigs move on the roller track)

spaces below the factory floor must be vented or sealed to protect them from accumulations of pentane gas.

The pentane gas detectors should be calibrated to detect emissions at 10% of the LEL. A warning should be given and an increase in extraction capacity should occur. If the pentane gas concentration continues to rise, an alarm should be given at 25% to 30% of the LEL and the production of cabinets or doors should be interrupted. The cause of increasing concentration should then be investigated.

Safe production

Safe production using pentane-blown rigid polyurethane foam systems is achieved by (1) identifying the critical work areas and production operations (Figure 14) and (2) applying the appropriate safety techniques and engineering standards.

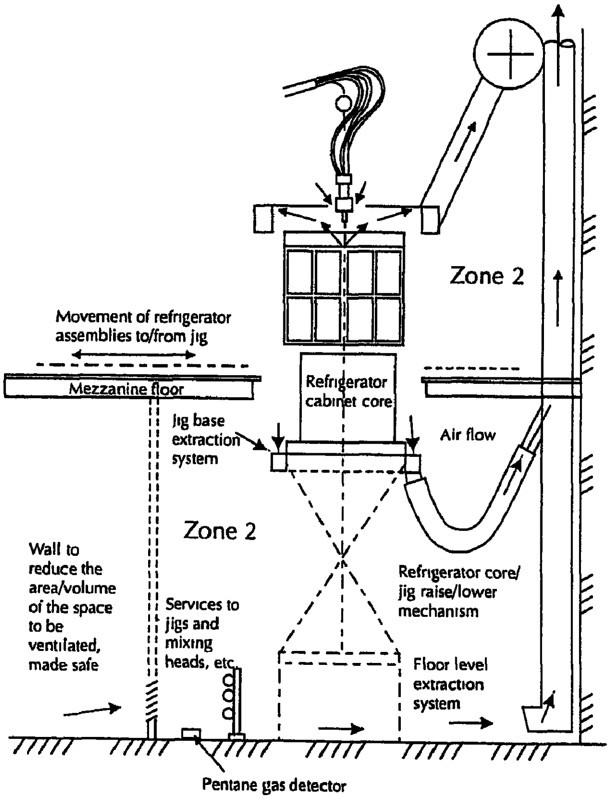

Zone 2
Movement of refrigerator assemblies to/from jig
Mezzanine floor
Refrigerator cabinet core
Jig base extraction system
Air flow
Zone 2
Wall to reduce the area/volume of the space to be ventilated, made safe
Services to jigs and mixing heads, etc.
Refrigerator core/ jig raise/lower mechanism
Floor level extraction system
Pentane gas detector

Figure 14. Movement of refrigerator assemblies to/from jig

Conclusion

Accidents and emergencies can and will occur/arise on the best designed and constructed production lines. With such events possibly giving rise to the emission of a flammable liquid or gas, it is important that the production line workers and factory management have clear and comprehensive emergency procedures to follow.

At the very least, staff must know what action to take when a pentane gas emission is detected and the alarm given. In the event of a breakdown or emergency, staff must not be left to take whatever action they feel is appropriate.

Summary of the panel discussion on cyclopentane foam blowing

Panelists

- Ms Lalitha B Singh
- A S Ghoshal
- M Srivastava
- M Sarangapani
- Walter Arasio
- J Kishan Rao
- N T Desai
- R S Iyer
- S K Mukherjee

Major issues

- On the safety concerns, it was commented that the use of hydrocarbons (HCs) in the refrigerator manufacturing industry should not be a major problem from the safety angle because India has more than 100 liquefied petroleum gas installations where conditions similar to that for refrigerator plants already exist. It was pointed out that all precautions, like earthing and antistatic flooring should be taken in the plants and also adequate ventilation systems be provided to ensure that the cyclopentane concentration remains below the minimum explosive limits.

- As per the existing petroleum rules, cyclopentane comes under Class A. The rules pertaining to storage and transportation in drums or bulk already exist and the same would be applicable for cyclopentane. Many petroleum products that come under Class A, like naphtha and gasoline, are already being extensively used in India.
- It was emphasized that since the use of cyclopentane for refrigeration insulation is now a proven technology, the industry must come forward to submit proposals for seeking grants from the Multilateral Fund.

Various questions on the technology issues were discussed. These were related to the dimensional stability of cyclopentane blown foam at lower temperatures, incompatibility of liners with HCFC141b (hydrochlorofluorocarbon) usage and the possibility of using cyclopentane in smaller plants. It was pointed out that cyclopentane can be used even in smaller installations provided the safety norms as practised in European plants were not compromised. However, it was felt that HCFC141b would probably be more suitable for smaller installations since ensuring proper safety procedures in these units would not be a very difficult task. To a specific query on whether the existing hand pouring methodology being employed by a small commercial appliance manufacturer can be used in cyclopentane-blown foams, it was suggested that it would not be safe to continue with manual filling in the cyclopentane technology. The additional costs incurred towards safety precautions can be partially taken care of by seeking grants from the Multilateral Fund. There is a provision to get up to 35% additional costs above the stipulated incremental costs for projects envisaging changeover to HC-based technologies. It was pointed out that in the case of refrigerators, the danger of fire does not exist because the foam is clad in an SS casing whether it is chloroflourocarbon-blown foam or cyclopentane-blown foam. However, in the case of building insulations, the ICI experience showed that the danger in both cases is similar.

Three major issues related to the usage of cyclopentane and the present status have been summarized below.

- Technological issue does not seem to be a problem now.
- As regards availability, it is possible to procure indigenously from petroleum industry. Till the market volume picks up, imports are a distinct possibility.
- As far as safety is concerned, standards exist for the use of HCs. In case any specific standards are required for cyclopentane usage, it can be taken up by the Ozone Cell.

Matters related to the availability of cyclopentane and safety concerns were discussed. The possibility of technology transfer for cyclopentane manufacture, capability of Indian petroleum industry to supply the required quantity/quality of cyclopentane, import duties on cyclopentane, and a number of related matters were also discussed. There was also a discussion on the possibility of non-availability of HCFC141b for developing countries like India once the present major domestic users of 141b in USA and Japan switch over to alternatives by 2002. It was informed that if cyclopentane is classified under pure chemicals, the customs duty will be 50%. However, it was told that if there was a genuine need to reduce the duty structure on this chemical, it can definitely be taken up by concerned ministries. On the safety issue, it was suggested that extreme care should be taken at the design stage itself to ensure that the natural flow of air must be towards a safer zone as good air flow would dilute the possibility of any increase in cyclopentane concentration in the factory premises.

SESSION IV

SERVICING OF REFRIGERATION APPLIANCES AND TRAINING NEEDS

Organization and skills in the Indian RAC repair and service market: an exploratory analysis

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Introduction

Repair and service of domestic refrigerators, air-conditioners, deep freezers, water-coolers, and other items are generally done outside the factory premises in India. These are usually carried out by individual micro-entrepreneurs, their mechanics, and helpers. They belong to what is popularly known as the 'informal sector' or the 'unorganized sector' of the refrigeration and air-conditioning (RAC) market. We have some impressions about the working of this sector but not many details.

In any process of technical change it is imperative to consider the needs of the informal sector. The very impetus for this study stems from the need to understand and possibly respond to the needs and concerns of the informal sector. The purpose is to carry this sector in the process of technical change that is affecting the RAC industry in India. What we have attempted here is to understand the RAC repair and services market in the informal sector.

The objectives of our study have been to answer the following questions:

- What are the qualification, job, and skill profiles in this informal sector?
- Where and how have people learned their knowledge and skills?
- What kind of repair are they doing?

This paper is a part of a larger study on *Skill Acquisition, Maintenance Practices and Institutional Arrangements for Training: A Study of Informal Sector Units in the Refrigeration Industry,* sponsored by Swiss Agency for Development and Cooperation (SDC). Copies of the study can be had from the author or from SDC, New Delhi.

- What are the linkages between informal and formal sectors in the RAC repair and services market?

This study is based on a reverse tracer survey conducted in the cities of Madras and Delhi. The survey covered about 400 entrepreneurs including:
- small entrepreneurs who own establishments or who operate from their homes;
- mechanics employed there; and
- helpers or apprentices who undergo on-the-job training with them.

This paper is divided into three sections. Section 1 presents some salient characteristics of the informal sector of the RAC market. This is followed by a description, in Section 2, of the on-the-job training that takes place in this sector. Section 3 presents highlights of the reverse tracer survey findings and some implications of the study.

Characteristics of the informal sector

The informal sector of the RAC industry seems different and, perhaps, in some respects, unique. It does not fall into the conventional description of enterprises that use rudimentary and traditional technology and business practices. Rather it falls into a modern enterprise activity for a number of reasons.

First, almost all of them deal with more sophisticated technology and input, such as electric power and industrial chemicals, and require precision work. Nevertheless, the sector is highly dependent on the organized sector for raw material and spares.

Secondly, this sector is heterogeneous – from service mechanics, who do not own premises, to those who own and operate fairly large operations related to AC assembling, acting as sub-contractors for authorized manufacturers or service centres, repairing highly sophisticated RAC items, etc. The range of experience found in the informal sector seems broad and wide. The heterogeneity is also related to the variety of markets and consumers which the sector caters to.

Thirdly, despite this being a modern activity, it is organized informally, and little is known about them. There are no common platforms in which entrepreneurs meet. There is also no systematic information available about them.

Fourthly, this sector provides employment and an opportunity for on-the-job training of a number of school graduates, educated youth and those with formal qualifications in RAC irrespective of the quality of the entry level training. There are limited opportunities for vocational education and training (VET) in India for educated youth. This sector, therefore, attracts them for two reasons: the ease of entry and the potential for self-employment.

Fifthly, the informal sector is in direct competition with manufacturers and service contractors for a share of the market. Small enterprises registered or otherwise are increasingly assembling a number of items such as domestic ACs and deep freezers, which were earlier manufactured only by the organized sector. Similarly, repair and services of RAC items manufactured by the organized sector are mostly carried out by the informal sector. The informal sector services seem more easily available and offer a cost advantage to consumers than those offered by the formal sector. Also some of these units were sub-contractors or authorized service agents for some of the large players in the industry until recently.

Finally, the informal sector seems adaptive and innovative. Most of the work undertaken here have been learned by experimenting and not necessarily through formal training. The enterprises, for instance, can repair and service RAC items made in different parts of the world using their experience and locally available tools. It consists of highly skilled and innovative entrepreneurs performing a variety of activities related to production and repair.

In sum, the informal sector is modern, innovative, and heterogeneous; yet remains subordinate and dependent on the organized sector. Its reach appears to be broad and have a substantial presence in the industry.

Despite the uniqueness, certain notions of the organized sector when applied to the informal sector, such as apprenticeship, recruitment, promotion, and instruction may need rethinking when related to the process of skill acquisition. There exists a near inseparability between training and actual work process in the informal sector since functional separation in a small enterprise does not really happen. Often training could not be accidental. This seems to be the nature of the RAC segment in the informal sector.

On-the-job training in the informal sector

For people with some general education and without any formal qualifications in RAC, and even for those with formal vocational education and training or entry-level qualifications, to become an RAC technician is possible in the informal sector. RAC repair and service units usually take interested and educated youngsters as helper or apprentice and provide opportunities for them to learn on a full-time basis to become mechanics. The young entrants constitute inexpensive labour for these units.

Alternatively, some enterprising VET trainees, while undergoing RAC course(s) in various educational institutions, attach themselves to informal sector voluntarily for hands-on practical training since it is not adequately available in these institutions. Similarly, a few job-oriented certificate courses offered by government/ private institutes arrange for students' practical training through selected and recognized informal sector units or enterprises.

For the sake of convenience, it is possible to look at the broad range of operations in the informal sector under two major categories, namely,

1. generalists, who are involved with *general repairs related to domestic refrigerators and air-conditioners (including car ACs), services and maintenance subcontracting, etc.; and*
2. specialists, *who perform a range of repairs related to compressors.*

On-the-job training informally takes place in each of these segments. There are sub-segments as well concentrating on a particular operation or a set of operations. Service and repair in RAC include the following operations not necessarily in the order presented.

- General fault finding - electrical, replacement of parts, etc., denting and painting of cabinets, servicing domestic ACs, gas charging of compressors, etc.
- Assembling domestic ACs using kits; service, repair, and maintenance
- Compressor repair - compressor starter winding and fitting
- All work related to piston, grinding of bush, valve plate, etc.
- Welding and painting compressors
- Car AC repairs

Some of these operations are explained below.

- ***General fault finding.*** Mechanics are interested with finding faults related to electrical problems, repair and replacement of worn out parts if any, denting tinkering and painting cabinets, and servicing; gas charging following all requisite procedures; replacing interior wiring, etc. Servicing of other domestic electrical appliances is also carried out as a survival strategy. Such mechanics may undertake more complicated repairs related to compressors but usually sub-contract this work to specialists.
- ***Assembling domestic ACs.*** People involved with this do a number of interrelated activities. First, using domestic AC kits that are available ready-made in the market, they assemble them and attach a compressor and charge them. This would be installed as requested by clients. Secondly, they also undertake annual service and maintenance contract for clients who have a large number of ACs. Entrepreneurs in this segment are in direct competition with branded manufacturers of domestic ACs.
- ***Compressor repair.*** Refitting worn-out compressors is a major activity in the informal sector. All work related to compressors requires special skill and falls under the categories listed below.
    - *Compressor starter winding and fitting operations.* When the compressor is cut open and the fault detected in the starter, mechanics rewind the starter. This is an intricate operation requiring considerable skill and understanding of

the gauge of copper wire to be used, insulation material, capacity of the compressor, etc.

- *Compressor motor repair.* If faults are in the motor, particularly related to piston crankshaft, valve-plate grinding, sleeves, bushing, etc., it is done by another set of specialists. Lathe and other instruments are required for this job. Once this work is completed and the motor is set right, the compressor fitters align the starter and the motor, check for other faults and refit the compressor.
- *Compressor welding.* The domes of the compressor are put together to weld them. This again is a specialized operation requiring high degree of skill to ensure that there are no leaks after welding. The compressor is then spray-painted by the same mechanics and is ready for use.
- *Car AC repair and service.* This is a highly specialized work. As the design of car ACs is different when compared to their domestic counterparts, not all AC mechanics would undertake this work. From detection of leaks in the compressor to refitting them in cars, all operations require deftness and understanding of intricate electrical mechanism. Furthermore, servicing of car AC also requires special tools and instruments.

In each segment described above, there seems to be a process of on-the-job training taking place. Unlike the formal education imparting institutional training that is generally theoretical and less practice-oriented, what a person acquires here is practical hands-on experience. A receptive mind and a willingness to work hard in arduous working conditions are essential to survive in this sector.

Many proprietors have undergone this process without receiving any payment initially. There was enough to learn, not only about technical matters but also other aspects of business. By closely observing the proprietor's way of handling customers, many reported having learned something new. Proprietors who are reasonably well-trained, transmitted skills to helpers through demonstration and direct supervision. Generally, since proprietors who were doing well had to constantly worry about business development, the onus of training mostly was on the mechanics employed in these units.

This being the reality, understanding the process of on-the-job training in the informal sector holistically would mean focusing on a number of interrelated issues such as: how do people enter the RAC trade, work process in the units or enterprise as perceived by the proprietor or entrepreneurs and the others particularly, mechanics and helpers or apprentices, the environment in which the enterprise is operating, the way it is responding, the manner in which the various actors, particularly entrepreneurs, are presenting themselves in everyday life, etc. On-the-job training, therefore, may be related to not merely technical aspects but may have important social and non-craft dimensions as well.

Some additional findings of the survey

- In Madras and Delhi, the informal sector units are spread all over. Some operations were concentrated in certain areas of the city (e.g. compressor repairs as in Delhi). The units could be located anywhere e.g. in market areas, housing colonies. Many operated from their homes, making it difficult for people to locate them.
- Entrepreneurs, mechanics, and helpers or apprentices are all educated. Almost 40% in Delhi and 60% in Madras have some formal qualification in RAC.
- Many of them possess wide ranging skills in repair and services. The units seem to have started during post 1980s.
- There is a general pattern of mobility from apprentice to mechanic and then graduating to a proprietor, depending on means, family support, etc. Some of the proprietors have moved further up by becoming entrepreneurs with a high volume business related to assembling ACs, repair of compressors, providing services contract, etc.
- Many of the proprietors and mechanics are aware of the usage of modern tools, gauges, etc. Many possess and use instruments that are made abroad. However, a good percentage acknowledged the limitations of their techniques, particularly about repair and maintenance.
- A large percentage of proprietors were keen on obtaining further training and admitted that they will not be able to survive in the future without skill upragadation.

Implications

The informal units have carved a unique position for itself within the RAC industry, with their technical capabilities. Contrary to popular belief that the informal sector consists of people without skills, enterprises in this sector have educated and skilled persons who are interested in further education and training.

The training needs or further education for informal sector has been an area neglected by governments, the organized sector, and a host of training institutions involved with VET. This sector has another major anxiety: would the choice of technology in RAC be employment-friendly or will it be such that they would progressively lose out to the organized sector?

Acknowledgements

The author is most grateful to Dr Urs Heierli, Mr Hansrudi Pffieffer, and Dr Cherian Joseph for useful discussions and numerous suggestions.

Concepts and experiences in servicing of refrigeration appliances (mainly isobutane/R600a)

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Introduction

Yesterday (13 February 1996) you have watched the practical demonstration of an R600a refrigerator repair with the Liebherr-designed equipment. It had been a long way, with new developments and practical experience, to come to this actual situation, where such equipment is freely available on the market. As a reminder, let us briefly examine how this happened, why was R600a chosen as refrigerant, and what are its main characteristics.

Until 1993, R12 has been used as a refrigerant in domestic appliances. In April 1993, we changed our whole production programme (nearly 400 basic models in two factories) to R134a within two weeks. Simultaneously, the whole service network was adapted to handle R134a, besides R12 too. This was not a difficult task, as the equipment needed for R134a is nearly the same as for R12. Only esther oil and different joints/sealings had to be used. We also recommended to use Lokring connections, as soldering creates oxidizations that will be dissolved by R134a. It can then create obstructions in the cooling circuit. As esther oil (R134a) and mineral oil (R12) do not fit together, we opted to supply all service stations with a second set of repair equipment for R134a. At the same time, it was obvious that R134a would not be accepted by German consumers for a long time, due to its high global warming potential (GWP). Hydrocarbon (HC) or blends of it were already known as refrigerants, but not yet ripe for mass production. The final decision was R600a. It is a flammable gas, with the chemical formula C_4H_{10} and has the following characteristics:

- ozone depleting potential (ODP) zero;
- GWP nearly zero;
- atmospheric lifespan of only two to three days; and
- a boiling point of −11.7 °C.

It is explosive as air mixture between 1.8 and 8.4 vol. %. It is colourless and odourless.

Liebherr started with R600a in February 1993, when first samples were produced and sold; mass production of specific R600a models started by mid-1993. As for the production, no real experience existed as to how to handle this gas in day-to-day business and according to the standards and regulations.

Service concept

To conceive a service concept for repairs in the cooling circuit of R600a appliances at the customers job-site, nearly the same conditions apply as for the mass production with HC R600a at the final assembly. These criteria are given below.

- To avoid any explosive mixture of gas/air
  (contrary to production, no gas detectors will be possible)
- No ignition source
  (the ignition temperature is around 530 °C)
- The quantities handled are rather small
  (approximately 20–50 g – like one or two small cigarette lighters)

First repair necessities arose by the end of 1992 at the German Foron company, which used a mixture of propane and isobutane. At that time, the gas used to get burnt out and filling was done with small cartridges, containing the exact-needed quantity. It was not a professional procedure at that time. Generally appliances were brought back to the factory for repairs.

Liebherr service concept

When Liebherr started in 1993 with first R600a models (only one or two), these cartridges were also used at first. But then intensive work began to conceive a professional concept, which was finalized in early 1994. The problems faced are given below.

- Filling the cylinder was not possible, as R600a does not have a plain surface in a bottle or cylinder. It lies higher at the border and lower in the middle. For the exact-filling quantity required, only weighing seemed feasible.

- To find flexible hoses resistant to R600a. A gas- and acid-resistant hose in the pneumatic sector was found ideal.
- To find a suitable quick connection valve (three-way). The Schrader valve was found suitable.
- Only parts approved by German TÜV could be used.

Other small problems were solved. Then we looked for an industrial partner to produce this equipment in larger quantities. Later on, it had been copied by other companies and is used everywhere currently.

The result of the above-mentioned developments and experiences is the service repair set that you had seen yesterday (13 February 1996). The components of this repair set are listed below.

- Filling device for R600a
  - Two bottles of R600a (net content 450 g each)
  - Set of manometer, precision regulating valve with filling hose and quick coupling
  - Digital precision scale
  - Portable case for these items
- Lokring equipment
  - Different tools for various kinds of Lokring connections
  - Valves
  - Filling tubes, reduction tubes of different materials
  - Alu case for above-mentioned items, portable
- Piercing pliers
  (for filter drier and filling tube)
- Connection couplings
- Leak detector

As the quantity of R600a in the cooling circuit is much smaller than for R12, we recommend to check the leak rate in an even smaller range. Hand-carried leak detectors with leak rates above 10 g per year should not be used. We use 3 g per year.

All items of this repair set are available in the market and can be purchased from special companies (Lokring, Refco, Kältefischer, etc.). The prices are roughly DM 3500 for the first four items (above) and DM 2500 for a good, reliable leak detector. Accessories such as nitrogen gas bottle and vacuum pump [two stage, 3.5 m^3/h (filled with esther oil, which is more hygroscopic than mineral oil)] are also available. This service concept is applied now by most of the main European refrigerator manufacturers.

A repair equipment (vacuum pump, filling device, Lokring, etc.) is also available these days, which can serve all three refrigerants (R12, R134a, and R600a), but with separate valves and hoses for each refrigerant.

Bosch-Siemens concept

Bosch-Siemens is the only company that did not use the before-mentioned procedure. They still use the initial system with various cartridges of different weight. The drawback of this system is that the simple valves used (for cost reasons) are not always 100% tight. For this reason, you are not always sure that you have really filled in the total quantity.

Servicing procedure

For any repair, you will need the above-mentioned equipment and you have to obey the basic conditions and instructions mentioned earlier. The repair procedure is given below.

- Exhaust the refrigerant on the pressure side into the open air.
  - Plug into the system with pliers at the filter drier first and connect hose.
  - Open the pliers and let discharge the refrigerant with the 5 m hose (out of the window).
  - Connect the compressor to the main electric supply (electric socket).
  - Let the compressor run for five minutes.
  - Pull out the plug for about one to two minutes, then have the compressor run another five minutes.
  - Close the pliers at the drier.
- Discharge the remaining refrigerant on the suction side.
  - Connect the second pliers with the vacuum pump. Plug in at the filling tube.
  - Evacuate the remaining refrigerant with the vacuum pump.
  - Once the pre-set absolute vacuum setting is reached, let the vacuum pump run on another 10 minutes.
  - Disconnect the vacuum hose and both pliers.
- Disconnect the pipe connections and prepare the new connections.
  - Cut all necessary connections.
  - Seal the pipe-ends with rubber caps.
  - Change compressor (if this is the defective part).
  - Begin working with the new compressor. Connect the pipes with the Lokring system. Blowpipes or open flames are never allowed.
  - When servicing with Lokring connections, follow manufacturer's instructions.
  - Use the service drier and apply Lokprep sealing compound sparingly.
  - Lokring connections must be made cleanly and carefully. Wait for three minutes after use of Lokprep before any pressure test.
- Pressure test with nitrogen.

  - Connect nitrogen bottle with filling tube.
  - Conduct a pressure test, but not above 8 bar.
  - Check all the connections (with a leak spray out of a bottle; it is a kind of soap water). Lower pressure and let the nitrogen escape.
- Evacuating.
  - Connect vacuum pump. Evacuate the suction and pressure side until it reaches the point of absolute vacuum. Let the vacuum pump run for another 10 minutes.
  - Connect the isobutane bottle with the valve and vacuum pump by means of the filling hose.
  - Before ending the evacuation process, the hose connection to the filling cylinder must also be evacuated to free the system entirely from all residual gases.
  - Check the isobutane cylinder. Make sure the degree of purity is 2.5. (Quality level on the 'Linde' bottles.)
  - The cylinder pressure must be above 1 bar; otherwise the pressure cylinder must be heated in warm water.
  - Open the cylinder valve.
  - Switch on the scales and measure the gas volume in the cylinder (by weight).
  - Adjust the tare to zero.
  - Open the hose valve to allow the refrigerant to flow into the cooling circuit. The refrigerant flows in slowly, allowing accurate filling. After about two minutes, switch on the compressor.
  - Filling should be accurate to a gram.
  - Close the hose valve and switch off the scales.
  - The filling operation is completed. Take off the quick-action coupling (Schrader valve).
  - Screw on the protective cap, after applying some Lokprep.
  - Check all the connections again with electronic leak detector.

A Liebherr service technician has the following equipment:

- a complete set for the use of R12, vacuum pump with mineral oil;
- a complete set for the use of R134a, vacuum pump with esther oil; and
- a complete set for R600a, the vacuum pump can be used from the R134a set.

Conclusion

The experience of the past few years has shown that HCs can be handled safely in production and after-sales service. Until today, Liebherr alone has produced more than one million R600a refrigerators and, in Europe, it will be more than three million. Not a single accident occurred during production nor in the use of these appliances. There had been, however, some minor incidents in the initial days of servicing, when R600a was burnt out. This is now avoided, when you use the proposed service equipment. Our actual service statistics shows that more than 60% of repairs are on R134a and only 40% on R12 and R600a put together.

General defect rates on R600a systems are similar to R12; whereas for R134a, it is double. In this connection, some remarks on our R134a experience are provided. We have been using R134a since April 1993 and will phase out its production by the end of 1996. Some of the problems with regard to and production servicing are listed below.

- Accumulation of paraffin in the system (compressor manufacturers' fault).
- In case of repair soldering, small oxidation occurs. These are dissolved by R134a and may block the capillary tube or spoil the valve reed (plate). This problem was solved with Lokring connections.
- Accumulation of humidity will block the system.
- Fifty per cent of service needs are related to noise problems. Accumulation of oil residues narrows the flow and creates noises like a 'waterfall'.

The repair consists of a rinsing from the suction side with warm refrigerant (50–60 g, 50 °C) and flushing with nitrogen to dissolve the oil residue. If too much oil is flushed out, a new compressor will be required.

- Production after change of shift
  - Components were left open (no rubber caps) during shift change. Result: Increase of humidity.
- Laying of appliances during transport
  - Esther oil is very thin and will flow into the evaporator. After it is set up, if the appliance is immediately put into operation, thickening and/or resinifications may occur and tie up the system, resulting in compressor failure.

With the introduction of R600a (isobutane), a non-ozone-depleting and energy-saving refrigerant, Liebherr has set new standards. Liebherr is committed to meet the ecological challenge by manufacturing environment-friendly products employing the very latest technology.

Training needs for servicing of refrigeration appliances

Jack Buswell
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Introduction

This paper is a supplement to the paper entitled 'Hydrocarbon refrigerants: properties, purity and safe handling' elsewhere in this publication. The extensive technical and safety information in that paper should form the basis of the training content for a serviceman handling 'Care' refrigerants [hydrocarbons (HCs)] in India. This content has been carefully developed and is well proven in the UK where some 1500 engineers and technicians have attended 51 Calor courses (as on December 1995).

However, there are obviously great differences between the refrigeration and air-conditioning industry in the UK/Europe and India. Before undertaking the analysis of HC training needs for India, five significant factors need careful scrutiny. They are (1) analysis of the needs, (2) fabricators/assemblers, (3) basic knowledge, (4) current quality/safety performance, and (5) institutional aspects.

Analysis of the needs

Virtually any problem in industry or commerce can be put down to insufficient staff training. Ten to twenty years ago, scientific management principles set great store by 'Training Needs Analyses'. Nowadays, most businesses are aware that training is only part of a solution to a problem. Some problems, which start as a perceived training requirement, turn out to be a design, machine or organization problem. It is recommended that the approach to this subject in India should firstly be a needs analysis before evaluation of the training requirements.

Fabricators/assemblers

The structure of refrigeration and air-conditioning industry in India includes many small assemblers of freezers and air-conditioners. The 'tolerance' of chlorofluorocarbons enabled these small enterprises to start up and flourish. Adoption of R134a, other hydrofluorocarbons, HCs, and mixtures thereof will involve fundamental changes in practice for these enterprises. Considerable training is required in this area, which would entail a broad training programme for all fabricators including such things as workplace layout, siting and storage of refrigerant, and competent supervision. Many fabricators will need basic training covering appropriate system design.

Basic knowledge

In Europe, regulatory frameworks over consumer protection, public liability, and health and safety are impediments to an unqualified person setting up as an appliance serviceman. The UK refrigeration and air-conditioning industry has a registration scheme involving an assessment of the knowledge and practical skills of refrigerant handling. HC refrigerants and their potential hazards are included in this assessment.

Clearly a serviceman's training on HCs will be dependent on his basic knowledge. In the UK, the HC training has been an 'overlay' on basic craft knowledge and skills. A person handling HCs in a home or public place without a good understanding of refrigeration components, operation of systems and correct service procedures will present extreme risks to life and property.

Current quality/safety performance

The Calor training course covers HCs as 'drop-in' replacement for domestic appliances. We recommend that there should be an assessment of any risks associated with particular appliances. Some units may have a known weakness or a propensity to failure. This information would be a vital part of the training.

'Institutional' aspects

The special training needs of India to accommodate and take full advantage of HC refrigerants will require commitment and contributions from the institutions involved. The panel discussions of this conference will provide an opportunity to explore ideas, agree on priorities, and direct the way forward.

Summary of the panel discussion on servicing of refrigeration appliances and training needs

Panelists

- A S Ghoshal
- S K Kinra
- V Subramaniam
- R Kumar
- Varadarajan
- D H Dixit
- K Sahdev
- J Singh
- S S Sidhu
- E Prasad
- V Joshi (Mrs)
- Stephan Sicars
- Jane Gartshore (Mrs)
- Juergen Melzer

Major issues

Technology

- Since the changeover for the technology is inevitable and India has a choice to go for either R134a or hydrocarbon (HC) refrigerants, it was felt that both the technologies should be compared and the problems of training, safety, and servicing will have to be addressed to suit the requirements.

- The issues of the service sector have to be addressed first before a major technology changeover takes place.
- Even large-scale manufacturers are unable to decide upon the technology to be adopted, thus making it difficult for small-scale manufacturers. The lack of clarity in the small-scale sector is mainly regarding the cost of conversion and the product.
- There are thousands of mechanics who follow their own methods of servicing. They need to be trained to adopt the changes.
- The market barriers for new technologies need to be identified.
- The manufacturers should come together for the same working proposition to recycle refrigerants to protect the environment.

Safety

- Safety was one of the major factors highlighted regarding the use of HC refrigerants. However, it was felt that technically, safety is not an issue. Nevertheless, as far as the cost and public perception are concerned, many of the refrigeration industries have had problems.
- The safety needs of the small-scale sector have to be established before they changeover to HC as foam blowing agent and refrigerants.
- Rationalization of safety rules must be done.
- The attitude of workers inside the factory needs to be changed in order to manufacture safe and reliable products.

Servicing

- There are 12–15 million refrigerators in the market, and half of them have come only in the last five years. Considering the lifecycle of a refrigerator, which is almost 15–20 years, it is certain that these refrigerators are going to stay for quite some time. The industry has to service all. Equipment, tools, etc. for handling multiple refrigerants must be discussed in greater detail and the informal sector is also burdened with the same problem.
- The organized sector has employed their own technicians only in 15–25 cities, whereas the other parts are handled by distributors.
- The malpractices in the servicing industry have to be sorted out by providing adequate training to the local servicing mechanics. Good service practices must be followed.

- Training needs, equipment and tools requirements, gauges, etc. are going to play a major role as most of the servicing is done by the unorganized sector who will be burdened with different tools and gauges. This is going to be a major concern.

Training

- The issue of how training actually takes place should be addressed.
- Proper strategy/training institutions should be framed to impart training to recover the refrigerants from the systems.
- The government has a strong role to play in imparting training and development of the manpower through various institutions such as industrial training institutes (ITIs).

Policies

- The procedures in project preparation, financing, and implementation should be streamlined.
- The role of Controller of Explosives should be clearly defined and should be made responsible for setting up standards for the import of refrigerants.
- Tax laws should be reframed to suit the requirements of the refrigeration industries.
- Forums for various activities (technology, safety, servicing, training, etc.) should be set up to discuss the major issues and resolve them within some fixed time limits.
- Decanting from big to small cylinders is not allowed. The problem is to fill from small cylinders to consumers' system. Some standard specifications as guidelines should be framed and finalized for the small-scale sector. The guidelines can be implemented through the organized sector or some other agencies.

The gist of the question and answer session is given below.

- Regarding cleaning a compressor burn-out system for HC, the same cleaning procedure as for R12 should be followed, and rinsing must be done with nitrogen from the suction side. The process tubes can be closed with lockring after filling it, which may be expensive. Otherwise, it can be done with plungers. Regarding safety, better ventilation practices must be followed.
- For preventing fire in a small-scale refrigeration/air-conditioning unit where leak-testing, charging, and testing are done in the same room, all the operations have to be executed one at a time. However, if they are done simultaneously, either the working place of R600 must be separated or a local exhaust system must be installed to get rid of the leaking gases immediately.

CONCLUDING SESSION

Concluding remarks

Othmar Schwank
Managing Director, Infras AG, Zurich, Switzerland

The last panel discussion brings us to the core point in technology transfer. The sessions of the first day and also the beginning of the second day were oriented towards technical issues. When we talk about technology transfer, naturally, technology is at the core. But when we go deeper, what ultimately matters is people, their education, training, and getting them acquainted to another way of manufacturing or servicing, of doing things, which are unavoidably related to chlorofluorocarbon phase-out.

May I make an observation at this point. We have been associated with similar discussions for the past two years, and I can identify two different ways of doing things. You can look at the entire country and the task you have to do. And then, if you look at what you, as an individual, can contribute to the paramount task of changing practices in this country, it will be very little and you get discouraged. I think by this approach, you may not be able to get into action. In the Ecofrig project, we experienced that we did not have the option to target the entire country. But we contacted individual companies, and with some we collaborated and went ahead step by step. And by designing actions, which can solve a problem, you can set the ball rolling. I think we should look out for small steps in order to do so.

Nobody in the country will advance just by looking into what needs to be done, and how many things need to be done to convert the entire RAC sector. It will come only if the initial steps are taken. And I am quite confident that the exchange during the day has been very useful from the number of responses we received during this conference. It was a pleasure for me to be present in that. Now from the Indian viewpoint, Dr Mathur will provide some more observations.

Thank you.

Concluding remarks – Indian viewpoint

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In the last two days, there has been a lot of discussion, and even shifts in the attitudes. I would like to summarize these, leading on to what the next steps should be and what the outstanding policy issues are.

One of the most important issues that has been highlighted is that, as far as hydrocarbon (HC) technology is concerned, safety is technically not an issue and, I emphasize the word 'technically'. It is an issue as far as costs and public perceptions are concerned. For cost reasons, it may be an issue in the servicing sector as well.

Secondly, the consensus for the general adoption of cyclopentane for foam-blowing in the domestic refrigerator industry is now in place. It is largely because of international technology trends, and the transitional nature of hydrochlorofluorocarbons (HCFCs).

Given this, what should be the next steps? Clearly, the next steps are project preparation, financing, and implementation; and here there are outstanding problems.

Some refrigerator companies have had problems in preparing a project that is acceptable to implementing agencies, the Government of India, and the Multilateral Fund. Therefore, we urgently need to streamline the issues and processes through which acceptability to all the institutions can be ensured.

The supply of cyclopentane, including the taxation structure associated with it, is an outstanding policy issue. This is, primarily, a matter of demand and, hence, of costs. This has to be addressed at a policy level.

In the commercial refrigeration sector, as regards large users, I find that most of them have already made the technical choice for foam blowing, and moved largely to HCFC141b.

In the small-scale sector, there is still a lack of clarity on the issue of costs – both costs of conversion and of the products. This uncertainty is basically related to the costs associated with safety. Consequently, the next logical step is the need to appraise safety and cost needs, and again to compare them on an equal footing with other options.

On the refrigerant front, HCs are a clear option for domestic refrigerators, including frost-free refrigerators. However, it does not enjoy the same type of consensus as a preferred option as cyclopentane enjoys for foam blowing. The issue of servicing is closely linked to this lack of clear consensus.

The next step is the identification of market barriers to the adoption of HCs as refrigerants. This has already been initiated, as was mentioned in the presentation by Mr Rahill from the World Bank. At the same time, protocols, training procedures, and tool packages for safe and competitive servicing need to be established. There is also a need to establish these processes even before we can go out and provide these services in others.

Finally, when it comes to commercial refrigeration, HC again is a clear technical option as a refrigerant for small- and medium-sized appliances. However, in the small-scale commercial refrigeration sector, the issue of costs of HC refrigerant is still outstanding. The next step is, therefore, an identification of the safety needs and an appraisal of costs as against other options. In this, the issue of taxation and its impact on the manufacturing is also something that needs policy examination.

Let me summarize. The next steps are as follows: (1) the appraisal of safety needs and costs both in foaming and as refrigerants in the small-scale sector; (2) the identification of market barriers to the adoption of HCs; and (3) development of protocols, training procedures, and tool kits for safe and competitive servicing.

Within this framework, it is important to define the most appropriate roles for various stockholders in this conversion process.

Finally, we come to outstanding policy issues. They are: (1) supply of cyclopentane; (2) streamlining of project preparation and financing procedures; (3) the rationalization of safety rules; and (4) the taxation and fiscal policies, especially related to the imports of these products, and with respect to the various products and sectors in which they are manufactured. Obviously all these steps require the creation of various forums where the stakeholders can continue to meet for these discussions. There is also certain timeliness in addressing these issues.

I think we would all go away satisfied if, we, in our own mind, set up some sort of time-frame for achieving these tasks. The next steps that we all think are essential should be initiated within the next three months. Policy issues should be discussed within three to six months. I think if we all try towards this, then this conference would be a success.

Thank you.

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